CRANFIELD UNIVERSITY
SCHOOL OF AGRICULTURE, FOOD, AND ENVIRONMENT
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NITROGEN MINERALISATION AND LEACHING LOSSES FROM FARM-YARD MANURE UNDER SIMULATED CENTRE PIVOT IRRIGATION

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ABSTRACT

Nitrogen (N) leaching losses resulting from agricultural activity are a major concern to researchers and land managers in different parts of the world, due to the adverse effects of dissolved nitrogen on the water environment and on farmers' returns. In this study the effects of intermittent irrigation, such as that occurring under centre pivot irrigation, on leaching losses of nitrogen mineralised by micro-organisms from different application rates of farm-yard manure (from 0 to 80 t FYM ha^{-1}) and N fertiliser (300 kg N ha^{-1}) mixed with sand have been examined using pots and leaching columns. Different N species (Ammonium, NH_4^+-N; nitrate, NO_3^--N; and total soluble nitrogen, TSN) have been investigated in the effluent samples collected from the bottoms of the pots and columns.

Initially, in the pot experiments the results showed that there were significant differences (P = 5%) between the amounts of nitrogen mineralised from the different FYM application rates under different wetting treatments. The moisture conditions had greater effects on nitrogen mineralisation than FYM application rates. However, the opposite was observed when the C:N ratio of the applied FYM was narrowed by the addition of urea as a N fertiliser. Nitrification did not occur in a mixture of FYM-sand (i.e., un-modified sand), which was attributed to the lack of nitrifying bacteria in the mixture. However, inoculating the mixture with a sandy loam field soil caused NO_3^--N to be the major N species in the effluent samples.

In the leaching columns, NO_3^--N was the dominant nitrogen form found in the effluent. NO_3^--N concentration was significantly affected by the irrigation practices.

The highest concentration (95 mg NO_3^--N l^{-1}) has been found for the treatment in which the top sections containing the applied FYM have been maintained at the field capacity moisture condition.

A relationship between the frequency of water application and NO_3^--N movement in the soil columns was found. The amount of NO_3^--N leached from the soil columns wetted every four days > eight days > twelve days. This suggests that frequent irrigation practices leach NO_3^--N further in the soil profile increasing the possibility of NO_3^--N leaching beyond the root zone.

In addition to water application practices, the start of NO_3^--N breakthrough was related to the moisture conditions of the soil columns. For the soil columns maintained continuously at the field capacity, 812 ml cumulative effluent was needed before the NO_3^--N breakthrough, compared to 610, 464, and 381 ml which were needed for the soil columns intermittently wetted for 4, 8, and 12 days, respectively. This indicates that more water is needed before NO_3^--N breakthrough under wet conditions than under dry conditions. The amounts of N leached from the soil columns were correlated with the ratio of effluent to water applied, suggesting that irrigation and drainage practices have an impact on NO_3^--N leaching losses.

This study has demonstrated that there are relationships between the frequency of irrigation and N mineralisation and leaching losses from the applied FYM, which lead to the conclusion that minimum NO_3^--N leaching losses are likely to be obtained under irrigated fields when adequate adjustments for the nitrogen mineralised from the applied FYM are made and proper irrigation scheduling is practiced. The best management of nitrogen, which aims to maximise crop yields and minimise environmental impact, is proposed for centre pivot irrigation in the Kingdom of Saudi Arabia.

DEDICATIONS

This piece of work is dedicated to my mother who passed away a few months before seeing me through. It is also dedicated to my father and the rest of my family members.

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All praises at the beginning are to the Almighty Allah who enabled me to achieve this study, which I hope is a useful contribution to the knowledge of humankind.

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LIST OF ABBREVIATIONS

FYM	farm-yard manure.
N	Nitrogen.
NO_3^--N	Nitrate-nitrogen.
NH_4^+-N	Ammonium-nitrogen.
TN	Total nitrogen.
TSN	Total soluble nitrogen.
OC	Organic carbon.
mg l^{-1}	milligram per litre.
FC	Field capacity.
PWP	Permanent wilting point.
AWHC	Available water holding capacity.
AWDL	Allowable water depletion limit.
WUE	Water use efficiency.
NUE	Nitrogen use efficiency.
dS m^{-1}	Decisiemen per meter.
BTC	Breakthrough curve.
KSA	Kingdom of Saudi Arabia.
MAW	Ministry of Agriculture and Water.
MOP	Ministry of Planning.
DESS	Department of Economic Studies and Statistics.
DGS	Department of General Statistics.
FAO	Food and Agriculture Organization.

CHAPTER ONE

GENERAL INTRODUCTION

THE ROLE OF NITROGEN IN AGRICULTURE AND ENVIRONMENT

INTRODUCTION:

Nitrogen (N) is one of the essential elements in plant nutrition and has a major role in plant growth. It is a part of all essential constituents of cells and a major part of amino acids joined through peptide linkages to form proteins, which are functionally enzymes catalyzing all biochemical processes. It is also an integral part of the chlorophyll molecule, that is essential for photosynthesis, and of nucleic acids, the DNA and RNA, in which patterns of plant growth and development are encoded (Tisdale & Nelson, 1975; Olson & Kurtz, 1982; Addiscott, ***et al.***, 1991). In addition, Olson & Kurtz (1982) have indicated that N is essential for carbohydrate utilization, a stimulant to root development and activity, and supportive to other nutrient uptake.

Accordingly, N is considered one of the most frequently limiting elements in crop production. Deckard, ***et al.*** (1984) indicated that increased grain yields and protein percentages resulting from the application of N fertilizer to N-deficient soils have long been recognized. Deckard, ***et al.*** (1984) also suggested that N has a major effect on the nutritional or industrial quality of most agronomic crops.

Thus, both N supply and management are key factors for meeting the increasing need for high-quality crops according to Deckard, ***et al.*** (1984), who also emphasized the fact that N management is an essential mean to establish a balance between yield and quality. Follett, ***et al.*** (1981) stated that proper amounts of the grain protein in wheat and corn, the sugar content of plants, and digestibility of forages are all secured by an adequate but not excessive N supply.

Bock & Hergert (1991) indicated that an early primary goal of N management in agriculture was to improve agronomic effectiveness and economic return, however N scope of interest has broadened to include environmental control since 1965. Further legislation passed in the 1970s and early 1980s shows the increased concern about environmental control (e.g., the possible groundwater pollution with nitrate, NO_3^--N) (Bock & Hergert, 1991).

This chapter aims to give a general background of N in agriculture and the environment. It is planned to discuss the following aspects:

1- N management.

2- Sources of N in agricultural soils.

3- N cycle.

4- Agricultural practices and N in soils relationship.

5- Excess of N and its impacts on natural resources.

6- The aims and objectives of the study.

1- N MANAGEMENT:

N best management is the one which efficiently accommodates crop N requirements with least environmental compensation (Keeney, 1982; Alderich, 1984). The aim of N best management is to maximize targeted crop yield and quality and to minimize adverse effects on environment and natural resources, which result from excessive N supply.

Olson (1972) stated that the main estimates required to determine N fertilisation management for enhanced crop utilization include an efficient chemical carrier of N and the rate, time, and method of application. Alderich (1984) suggested a series of sequential steps to achieve optimum N fertilizer practices to ascertain the highest possible agronomic returns and the least unwanted environmental consequences. These steps are as follows:

i- Estimate the possible yield based upon previous experience or upon yield potentials developed by agricultural colleges or research centres.

ii- Estimate the amount of N which becomes available from the soil during the growing season. This includes the N inherent in soil organic matter, N from residues of preceding crops, and N carried-over from previous applications.

iii- Consider the N supplied from outside sources (e.g., animal manure, sludge, precipitation).

iv- Decide upon the amount of N fertilizers required for optimum economic return modified to the extent feasible by environmental considerations.

v- Select the best time and method of application.

This shows that N best management is achievable when the proper rates of N fertilizer are applied at the right time in the right place. These rates therefore have to account for all possible sources of N in the ecosystem. Thus, obtaining an adequate knowledge regarding these sources is a key factor in sustaining N best management.

2- SOURCES OF N IN AGRICULTURAL SOILS:

N exists in four recognized spheres of the Earth. These spheres are Lithosphere, Atmosphere, Hydrosphere, and Biosphere. The approximate inventory of N in these spheres is given in Table 1.1 (Stevenson, 1982a).

Table 1.1. Inventory of N in the four spheres of the Earth (Stevenson, 1982a).

Spheres	Tg of N*
Lithosphere:	1.64×10^{11}
igneous rocks:	1.63×10^{11}
of the crust	1.00×10^{9}
of the mantle	1.62×10^{11}
core of the earth	1.300×10^{8}
sediments (Fossil N)	$3.50\text{-}5.50 \times 10^{8}$
coal	1.00×10^{5}
sea bottom organic compounds	5.40×10^{5}
terrestrial soils:	2.400×10^{5}
organic matter	2.20×10^{5}
clay-fixed NH_4^+	2.00×10^{4}
Atmosphere	3.86×10^{9}
Hydrosphere	2.30×10^{7}
Biosphere	2.80×10^{5}

* Tg = terrogram = 10^{12} g or one million metric tonne.

Table 1.1 shows that N distribution is widely variable among the spheres, the Lithosphere, for instance, contains nearly 98% of the N bulk, whilst other spheres hold only 2 % of which most (1.98%) is in the atmosphere.

The remaining 0.02% of the Earth's N is contained in terrestrial humus, lakes, streams, sea bottoms, and living organisms (Table 1.1). This comparatively negligible amount of N however possesses a remarkable importance to plant and animals, because it is in a continual state of flux, flowing within and through complex internal cycles of the biosphere and interacting with the atmosphere (Hauck & Tanji, 1982).

It is therefore important to examine the N cycle in soil to understand about this continual state of N flux that regulates N to be available to or away from the growing crops. Accordingly, N best management may perhaps be achieved.

3- NITROGEN CYCLE:

This section aims to discuss the followings:

1- The general N cycle.

2- Factors affecting the processes of N mineralisation.

3.1- THE GENERAL N CYCLE:

Figure 1.1 shows the general N cycle in soil from the perspective of agricultural activity. This general N cycle is an integral part of the overall N cycle in nature.

Figure 1.1 shows that along with the N fertilizer application there are other N sources, which also supply N to growing plants. These sources are as follows:

i- Atmospheric depositions, that include:

  a- Wet precipitation as NO_3^--N washed down in rainfall.

  b- Dry deposition as solid particulates transferred by wind from one locality to another.

ii- Biological N_2 fixations, which are:

  a- Symbiotic N_2 fixations by micro-organisms (*Rhizobium*) living in symbiosis with host plants (generally legumes).

  b- Non-symbiotic N_2 fixations by blue green algae or by free-living bacteria in aerobic conditions (*Azotobacter*) and anaerobic conditions (*Clostridium*).

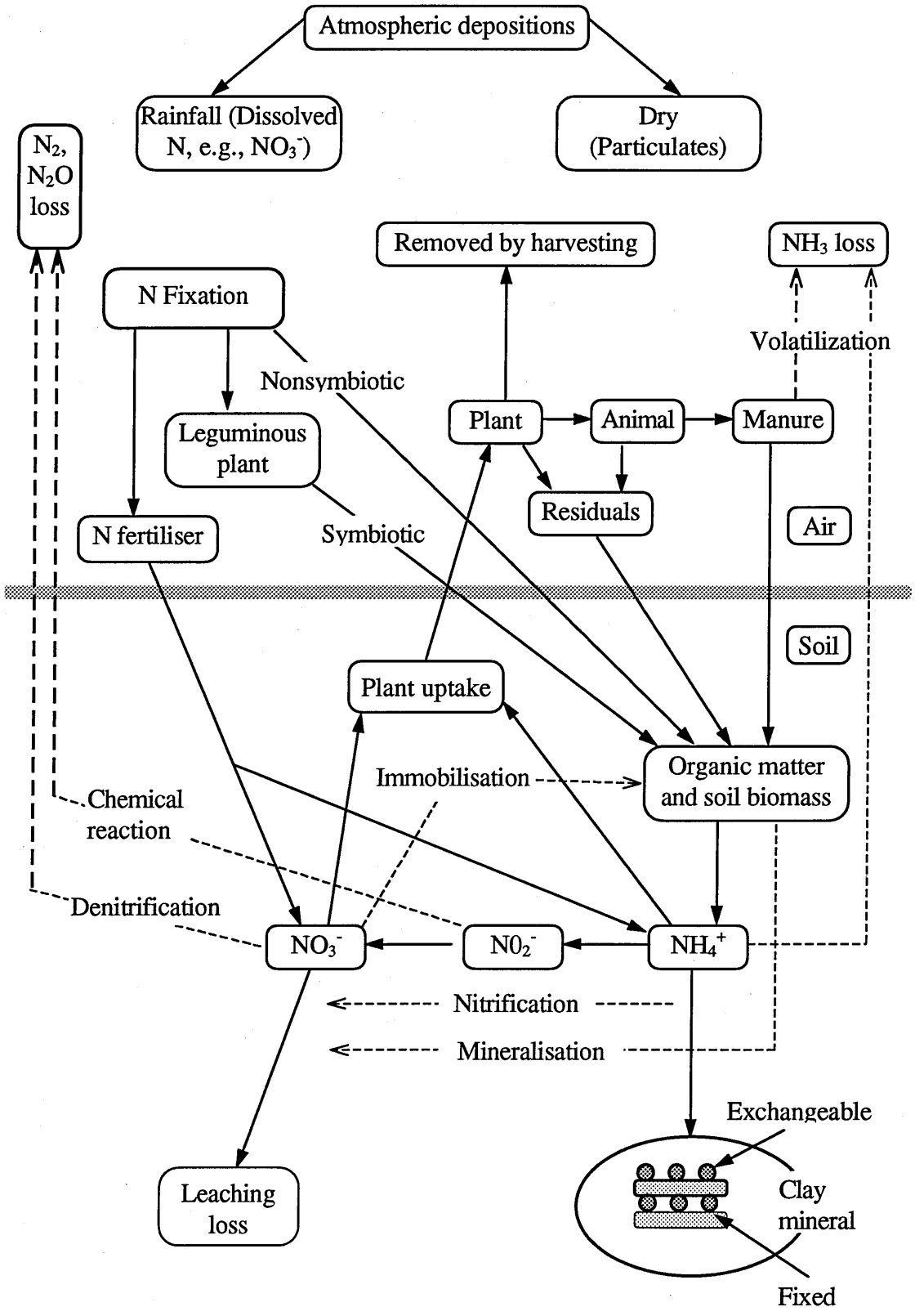


Figure 1.1. The general N cycle in agricultural soils.

iii- Mineralisation of soil organic matter (SOM), which is a biologically mediated conversion process of organic N forms to inorganic N forms. The mineralisation process comprises two steps, which are:

a- Ammonification that is the initial conversion to NH_4^+-N carried out by various non-specialized organisms.

b- Nitrification that is the oxidation of NH_4^+-N compound to NO_3^--N carried out by specialized organisms, *Nitrosomonas* oxidising NH_4^+-N to nitrite (NO_2^--N) and *Nitrobacter* oxidising NO_2^--N to NO_3^--N.

As a source of N to plants, mineralisation of SOM is more effective than the other two, because most of soil N occurs in SOM. Surface layers of most soils for instance contain more than 90% of their N in organically combined forms (Stevenson, 1982b). This organically bound N is unavailable to growing plants until it is transformed into inorganic forms of N (e.g., NH_4^+-N and NO_3^--N) (Wild, 1988).

Figure 1.1 also shows that N is in a dynamic interaction between various systems and forms involved in the cycle. Stevenson (1982a) indicated that besides the interaction with the total ecosystem an internal cycle operates causing N to be converted from one regulated system to another through a variety of biochemical and chemical processes. Stevenson (1982a) also suggested that the transformation of N species from one form to another occurs naturally in a completely irregular or random fashion.

These irregularities of N transformation result from the effects of different factors on the processes involved in transforming the N between the different systems or forms. The following section discusses the process of N mineralisation and the factors affecting its contribution to the total mineral N in agricultural soils.

3.2- FACTORS AFFECTING THE PROCESSES OF N MINERALISATION:

N mineralisation is performed by heterotrophic soil organisms, which utilize nitrogenous organic substances as an energy source (Jansson & Persson, 1982). Accordingly, the amounts of N mineralised from soil organic materials, whether indigenous or applied, depend on the population and activity of the micro-organisms

carrying out the process. As a result, factors affecting the process are associated with those regulating micro-organism growth and performance.

The following section discusses the factors which influence the biologically mediated processes of N transformation indicated in Figure 1.1 with emphasis on those affecting the processes of N mineralisation (the process of N release) and nitrification.

3.2.1- Ratio of carbon to nitrogen (C:N ratio):

N mineralisation from organic materials is a process carried out by different types of micro-organisms, as already indicated. These micro-organisms require mineral N for their cell synthesis in addition to their requirements for carbon (C), which they obtain from the organic material. Energy for their synthesis is obtained from the respiration and the oxidation of these organic materials (Schmidt & Belser, 1982; Wild, 1988).

The process of mineral N transformation into organic N however is called immobilization. Jansson & Persson (1982) indicated that in dealing with mineralisation and its role in the autotrophic phase of the biological cycle (i.e., plant production), immobilisation cannot be neglected, because in all mineralisation activities there is a component of immobilisation, a renewal of organic matter.

The balance between N mineralisation and immobilization is governed by different factors, among which, and the most important, is the C:N ratio of the material undergoing the decomposition (Franco & Munus, 1982; Wild, 1988, Tisdale, ***et al.***, 1990; Troeh & Thompson, 1993; Vinten & Smith, 1993).

Haynes (1986a) states that the critical C:N ratio within which net mineralisation occurs is generally in the range of 25:1 or less and also indicates that for C:N ratios greater than 30:1 net immobilization will generally occur resulting in a net importation of N from the system surrounding the organic material compounds. These values of C:N ratio have been also reported by other investigators (Jansson & Persson, 1982; Franco & Munus, 1982; Black, 1984; Archer, 1988; Wild, 1988; Tisdale, ***et al.***, 1990; Troeh & Thompson, 1993; Barber, 1995).

Figure 1.2 illustrates digrammatically the changes in mineral N between the processes of mineralisation and immobilisation as the C:N ratio of the materials undergoing decomposition alters with time (Tisdale, ***et al.***, 1990).

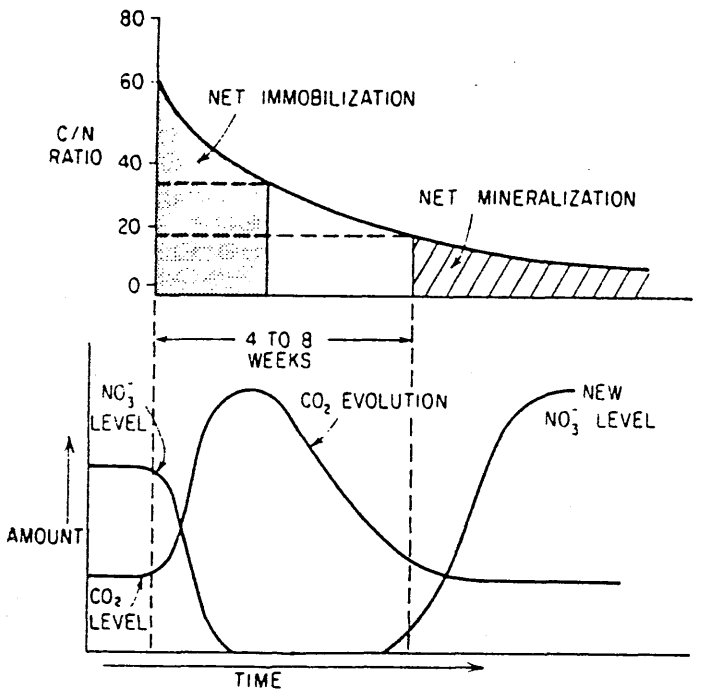


Figure 1.2. The change in soil mineral N (NO_3^--N) levels during the decomposition of low-N organic materials (Tisdale, ***et al.***, 1990).

3.2.2- Moisture:

Soil moisture has a considerable influence on N mineralisation and nitrification in two ways. One is by affecting the growth of micro-organisms, and the other is through aeration (Haynes, 1986a; Wild, 1988; Paul & Clark, 1996). The optimum soil moisture for both processes is between 10 and 33 kPa, the range in which the field capacity occurs (Justice & Smith, 1962; Birch, 1964; Reichman, ***et al.***, 1966; Sabey, ***et al.***, 1969; Agarwal, ***et al.***, 1971a; Adriano, ***et al.***, 1974; Stanford & Smith, 1972; Stanford & Epstein, 1974; Focht & Verstraete, 1977; Schmidt, 1982; Haynes, 1986a; Tisdale, ***et al.***, 1990).

The rates of both processes tend to decrease when the optimum moisture condition is decreasing due to moisture stress or increasing due to lack of O_2 (Haynes, 1986a & b; Schmidt, 1982; Wild, 1988; Paul & Clark, 1996).

Under dry conditions, micro-organisms performing N mineralisation are more tolerant to moisture stress than nitrifying bacteria, which can perhaps cause an accumulation of NH_4^+-N in dry conditions (Tate, 1995). This can be seen from Figure 1.3 (Schmidt, 1982), which shows the effects of moisture conditions on both processes.

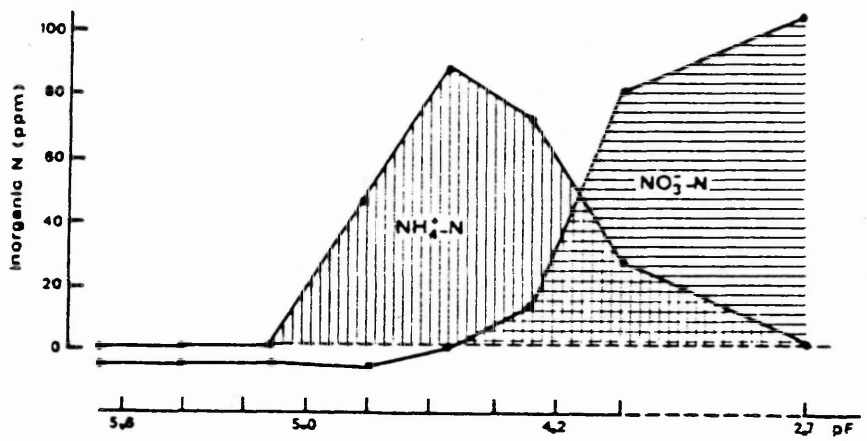


Figure 1.3. The influence of soil moisture conditions (pF) on the accumulation of NH_4^+-N and NO_3^--N in soil (Schmidt, 1982).

Lack of O_2 under very high soil water content decreases the biological activity and decomposition (Haynes, 1986a; Wild, 1988; Vinten & Smith, 1993; Paul & Clark, 1996). Wild (1988) suggested that when soils become so wet that the large pores are saturated, decomposition is limited by the diffusion rate of O_2 to the sites of microbial activity. Haynes (1986a) indicated that decomposition under anaerobic conditions is dependent on anaerobic bacteria (e.g., Clostridia strains), which function at a slower energy level and are less efficient than aerobic organisms. Nitrification is also affected by the lack of O_2, as the process is an oxidative one and does not occur at redox potentials below +200 mV (Wild, 1988).

Also, the increase in wetting condition affects other N transformation processes (e.g., denitrification). Figure 1.4 shows the relationship between microbial activity and water-filled pore space of soil (Linn & Doran, 1984).

Intermittent wetting/drying conditions increase N mineralisation and nitrification (Birch, 1964; Campbell & Biederbeck, 1982; Haynes, 1986a; Wild, 1988; Tate, 1995). Birch (1960) however indicated that the amount of N mineralised decreases slightly with successive re-wetting cycles. Semb & Robinson (1969), quoted by Wild (1988), found that flushes of NO_3^--N between 13 and 180 kg ha^{-1} occurred in 13 soils from different regions of East Africa shortly after the onset of seasonal rains.

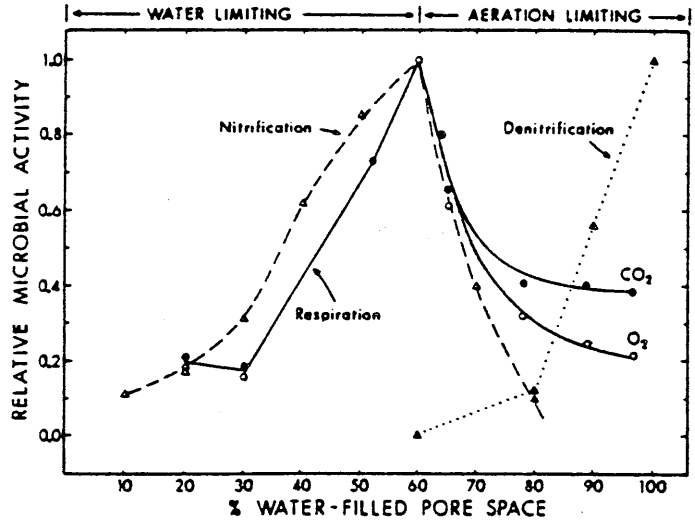


Figure 1.4. The relationship between the microbial activity and water-filled pore space of soil (Linn & Doran, 1984).

3.2.3- Temperature:

Temperature is a major factor affecting the decomposition of soil organic materials. Decomposer micro-organisms have different optimum temperature and growth ranges (Alexander, 1977; Haynes, 1986a). Alexander (1977) indicated that each biochemical step involved in the N mineralisation sequence is catalyzed by a temperature-sensitive enzyme, which is produced by micro-organisms whose growth is conditioned by temperature.

Thus, the process of N mineralisation occurs over a wide range of temperature from around freezing to 60°C, with an optimum value in a range from 45 to 60°C (Alexander, 1977; Haynes, 1986a).

Stanford & Smith (1972) indicated that rate of soil mineralisation is in proportion to the amounts of potentially mineralisable N (*N*) present in the soil at any time (t) according to the expression:

$$-dN/dt = k/N$$

where k is the constant rate of soil mineralisation (0.054 $week^{-1}$), which did not differ significantly among a wide range of soils incubated at 35°C and at optimum soil water content. The values of k however varied with temperature in the range of 5 to 35°C, suggesting that the amounts of N mineralised are doubled for every 10°C increase (Q_{10} = 2). Addiscott (1983) also indicated in a laboratory study investigating mineralisation of organic N in three Rothamsted soils with contrasting histories that the rate constants (k) were significantly related ($P < 0.001$) to the absolute temperature by the Arrhenius equation:

$$\ln k = \ln A - (B/T) \qquad (A \text{ and } B \text{ are constants}).$$

Tabatabai & Al-Khfaji (1980) observed that the amounts of N mineralised increased as the temperature increased from 20 to 35°C, resulting in averages of amount of N mineralised 3.8 and 16.6% of the soil total organic N, respectively. At 20°C, the rate of N mineralised was 2.9 μg g^{-1} soil $week^{-1}$, but increased to 12.5 μg g^{-1} soil $week^{-1}$ at 35°C. Tabatabai & Al-Khfaji (1980) suggested a Q_{10} value of 3. A value of Q_{10} varying from 2 to 3 is also reported by other investigators (Wild, 1988; Vinten & Smith, 1993).

Nitrifying bacteria were apparently found to be capable of adapting to climatic conditions, which explains the various temperature optima reported by different investigators (Focht & Verstraete, 1977; Schmidt, 1982; Haynes, 1986b; Wild, 1988). Mahendrappa, ***et al.*** (1966) observed in an experiment studying the oxidation of $(NH_4)_2SO_4$ added to different soils of western USA incubated at 20, 25, 35, 40°C under 0.3 bar moisture tension that nitrification was faster between 20 and 25°C than between 35 and 40°C in all soils from the northern regions, but for soils from the southern regions nitrification was fastest at 35°C.

Nitrification occurs in a wide range of temperature varying between 5 and 40°C, with an optimum value usually lying between 25 and 35°C (Frederick, 1956;

Alexander, 1977; Focht & Verstraete, 1977; Schmidt, 1982; Haynes, 1986b; Wild, 1988; Paul & Clark, 1996). For 5°C > temperature > 40°C, the rate of nitrification is very slow.

Over the range of temperature normally observed in a field, sensitivity of both mineralisation and nitrification to fluctuating temperature did not show major differences. Addiscott (1983) concluded that the Arrhenius relationships showed no significant differences ($P < 0.05$) between the sensitivity of mineralisation and nitrification studied in three Rothamsted soils at temperatures varying from 5 to 25°C. Stanford, ***et al.*** (1975) found that different sequences of fluctuating temperatures for 5, 15, 25, and 35°C imposed on soils during different incubation periods (0-16, 16-32, and 32-52 days) caused no effect upon the amount of N mineralised. However, this relationship is not true at temperature near freezing, where nitrification is more sensitive (Justice & Smith, 1962; Campbell & Biederbeck, 1982; Haynes, 1986b; Vinten & Smith, 1993).

3.2.4- Acidity (pH):

Soil pH affects the processes of N transformation in a number of ways. Kamprath & Foy (1985) indicated that soil pH is an important factor in determining the kinds, amounts and activities of micro-organisms involved in transforming soil organic materials.

N mineralisation is not especially sensitive to a particular optimum pH (Adams & Martin, 1984; Haynes, 1986a), because the mineralisation of native organic N is carried out by a diverse range of microflora according to Alexander (1980), quoted by Haynes (1986a). However, decomposition proceeds more readily in neutral than in acid soils (Haynes, 1986a). Killham (1994) suggested that the neutral pH is the soil reaction condition favourable for most soil bacteria.

For nitrification, a pH value between 7 and 8 or slightly higher is optimum for nitrifying bacteria (Frederick, 1956; Alexander, 1977; Focht & Verstraete, 1977; Schmidt, 1982; Adams & Martin, 1984; Haynes, 1986b; Wild, 1988). For autotrophic nitrification a pH of 4.5 was found to be the lower limit, at or below which nitrification under heterotrophic conditions could be of some significance (Focht & Verstraete,

1977; Haynes, 1986b; Kuenen & Robertson, 1988). In an agricultural situation, however, Focht & Verstraete (1977) suggested that one is normally dealing exclusively with autotrophic micro-organisms.

The optimum pH for denitrification is within the 7.0 to 7.5 range (Adams & Martin, 1984), and high NH_3 volatilization is likely at pH values of 9 or more (Miller & Donahue, 1995; Schmidt, 1982; Addiscott, ***et al.***, 1991).

In addition, N transformation processes are known for their effects on soil pH status. Mineralisation causes a rise in pH, whereas nitrification causes acidification. The mechanisms causing the rise or fall in pH due to N transformation processes are as follows:

Hydrolysis of ammonical compounds results in NH_3, which is then ionized with water yielding OH^-, causing a rise in pH status in the vicinity (Schmidt, 1982; Addiscott, ***et al.***, 1991). This NH_3 ionisation and OH^- production is summarised as:

$$NH_3 + HOH \leftrightharpoons NH_4OH \leftrightharpoons NH_4^+ + OH^-$$

Ionisation of NH_3 ($pK_a = 9.0$) is a function of pH. Schmidt (1982) indicated that the percentages of non-ionised NH_3 are 0.1, 1.0, 10.0, and 50 at pH 6.0, 7.0, 8.0, and 9.0, respectively. Thus in soils with pH greater than 7.5, NH_3 may occur in levels restricting the activity of *Nitrobacter,* leading to an accumulation of NO_2^--N (Schmidt, 1982; Haynes, 1986b).

However, these inhibitory effects of NH_3 on *Nitrobacter* causing the accumulation of NO_2^--N in soils is evident primarily during the early stages of decomposition (Morrill & Dawson, 1967; Wild, 1988).

Also, N- containing compounds such as proteins and amino acids are simplified by hydrolytic, reductive, and oxidative microbial activities during the process of organic material decomposition in soil (Follett, ***et al.,*** 1981). According to Tisdale & Nelson (1975), the changes in pH resulting from the decomposition process of organic materials can be expressed as follows:

$$\text{proteins} \rightarrow R\text{-}NH_3 + CO_2 + \text{energy} + \text{other products} \qquad \text{[Aminization process]}$$

$R\text{-}NH_3 + HOH \rightarrow NH_3 + R\text{-}OH + energy$ [Ammonification process]

N aminization and ammonification are part of the processes of N mineralisation, which proceeds to the nitrification process in the presence of nitrifying bacteria. Schmidt (1982) and Killham (1994) indicated that nitrification usually causes a decrease in pH value, which can be summarised as follows:

$NH_4^+ + 3/2\ O_2 \rightarrow NO_2^- + H_2O + 2H^+$ F -65 kcal. by *Nitrosomonas*.

$NO_2^- + 1/2\ O_2 \rightarrow NO_3^-$ F -17.8 kcal. by *Nitrobacter*.

Also, the biological process of urea hydrolysis (Tisdale, ***et al.***, 1990) causes soil alkalinity through the production of NH_3, which then undergoes the ionisation process resulting in OH^- group causing the rise in pH, as already indicated. The urea hydrolysis is described in the following formula:

$$CO(NH_2)_2 + H_2O \longrightarrow H_2NCOONH_4 \longrightarrow 2\ NH_3 + CO_2$$

3.2.5- Salinity (EC):

Excessive salt concentrations were found to affect microbial activity adversely, and so the processes of N transformation (Singh, ***et al.***, 1969; Agarwal, ***et al.***, 1971b; Hendrickson, ***et al.***, 1978; Makki, 1982; Reice & Herbst, 1982; Wood, 1989; Chander, ***et al.***, 1994).

It was suggested that there was no apparent effects of salinity on ammonification, but increased salinity progressively decreased nitrification (El-Shahawy & Mashhady, 1984; McClung & Frankenberger, 1985). In fact, salinity (osmotic effects) may contribute to N mineralisation, depending on the nature of salts and soils (Broadbent & Nakashima, 1971; El-Shahawy & Mashhady, 1984). Agarwal, ***et al.*** (1971b) concluded that both cation and anion species affect N release from the organo-inorganic complex or in exchange reactions involving adsorbed or fixed ions in the soil.

Singh, ***et al.*** (1969) concluded that chloride salts of mono-, di-, and tri-valent cations reduced CO_2 production, however NH_4^+-N release was enhanced by the cations in the order named.

Wild (1988) suggested that part of the adverse effects of salinity on nitrification is due to osmotic pressure and part to specific toxicity. The effects of salinity on nitrification and NH_3 volatilization varied depending on N source, amounts and types of salts, and the soil. Salinity promoted NH_3 volatilization in 2 days, meanwhile NH_3 losses were reduced by Ca^{2+} (McClung & Frankenberger, 1985).

Groffman, ***et al.*** (1995) studied the effects of KCl, KBr and pentfluoricbenzoic acid (PFBA) of 100 mg kg^{-1} concentration on soil respiration, N mineralisation, N nitrification and N denitrification. Groffman, ***et al.*** (1995) found that soil respiration as an index of microbial activity was reduced 50% in 2 days, nitrification was 10% less than the control, and mineralisation was decreased 35% of the control in the Cl^- and Br^- treatments.

McCormic & Wolf (1980), quoted by McClung & Frankenberger (1985), indicated that addition of 250 µg NaCl per gm soil reduced NO_3^--N levels in a sandy loam, but complete inhibition to nitrification occurred when 10,000 µg gm^{-1} was used. Also, it was suggested that Cl^- had no effect on nitrification at concentration less than 7400 µg l^{-1} (Monaghan & Barraclough, 1992).

This leads us to conclude that the effects of these factors on both N mineralisation (N release) and nitrification have a broad range. As already discussed here, the process of N mineralisation occurs under a wider range of these factors than nitrification, which was attributed to the diversity of micro-organisms performing N mineralisation.

These factors however are affected by agricultural practices possibly carried out over a large area, which result in different forms and amounts of N in soil and the environment. The following section discusses the relationship between agricultural practices and N in soils.

4- AGRICULTURAL PRACTICE AND N IN SOILS RELATIONSHIP:

Much previous research has been undertaken to determine the effect of several agricultural practices on the amount of N in soils to achieve N best management. Among those practices, and perhaps the most important in several areas of the world, are:

1- Application of farm-yard manure (FYM) and N fertilisers.

2- Irrigation practices.

The following discussion aims to review the roles of these agricultural practices in increasing N in soils.

4.1- APPLICATION OF FARM-YARD MANURE AND N FERTILISERS:

Some results of long term studies have indicated the existence of a relationship between the increase in soil N content and application of FYM and inorganic N fertilisers (Johnston & Poulton, 1976; Jansson & Persson, 1982; Haynes, 1986a; Christensen, 1988; Glendining & Powlson, 1991; Chambers & Smith, 1992; Glendining, ***et al.***, 1992).

Johnston & Poulton (1976) indicated that application of 35 t FYM ha^{-1} $year^{-1}$ from 1852 to 1901 caused N to accumulate in soil, but once FYM dressing ceased in 1901 soil N decreased. Chambers & Smith (1992) found that application of cattle/pig FYM caused elevations in soil mineral N concentrations in a range between 1% to 9% of total N applied. Chambers & Smith (1992) also suggested that the quantity of NH_4^+-N supplied by the FYM and slurries applications is highly significantly correlated (r = 0.926, P = 0.1%) with measured elevations in soil N supply, providing the slurry applied to the arable stubbles was quickly incorporated within 6 hours.

Christensen (1988) found from a study conducted on selected plots in the Askov Long-term (1894-1984) Fertiliser Experiment in Denmark that application of both FYM (i.e., manure + urine from 1894 to 1972, and animal slurry from 1972 to 1984) and N fertiliser (NPK) increased the total soil N content from 0.94 mg N per gm soil dry matter for non-treated samples to 1.43 and 1.16 mg N per gm soil dry matter (40% and 23%) for the FYM and NPK treated samples, respectively.

Glendining, ***et al.*** (1992) suggested that long continuous applications of N fertiliser to the Broadbalk Wheat Experiment increased both the total soil N content and the amount of N mineralised. The results showed a 20% (0.5 t N ha^{-1}) increase in the total soil N in the top 0-23 cm after the application of 144 kg N ha^{-1} $year^{-1}$ for 130 years since 1852.

It is important to recognise that increases in soil N content as a result of N fertiliser application occur over long time scales. Results obtained from the Broadbalk Experiment, Rothamsted showed that measurable changes in soil N content occurred within 15 to 20 years when large amounts of N fertiliser (142 kg N ha^{-1} or more) are applied (Glendining & Powlson, 1991).

In addition, an apparent increase in amount of N mineralised following the application of N fertilisers has been observed. Reviewing the results obtained from different long-term experiments (Broadbalk and Hoosfield, Rothamsted, UK; Deherain Experiment, Grignon, France; Swedish M Series of Soil Fertility Experiments, Skane, South Sweden; and Lethbridge Rotation Experiment, Alberta, Canada), Glendining & Powlson (1991) showed that there are considerable increases in the amounts of readily mineralisable N after inorganic N fertilizer applications for many years. These increases were, however, greater than the changes in total soil N content.

The priming effects of N fertiliser addition on mineralisation of soil N have been suggested as partially real and partially apparent (Jansson & Persson, 1982; Haynes, 1986a). The application of N fertiliser to the soil may stimulate the activities and population diversity of soil microbial biomass through changes to the microbial surroundings, which possibly alter the rate of N mineralisation.

In addition, the application of N fertiliser to soil promotes the development of plant roots, which may ameliorate the soil body (i.e., improve soil aeration) and contribute to increases in soil organic matter. Thus, these changes are likely to alter the rate of soil N mineralisation (Jansson & Person, 1982; Haynes, 1986a; Vinten & Smith, 1993). Also, soil organic matter was observed to increase with the addition of FYM (Sommerfeldt & Chang, 1985; Heggi & Abou-El-Ezz, 1988; Sommerfeldt, ***et al.***, 1988; Christensen, 1993), which may contribute to the change in the rate of soil N mineralisation (Haynes, 1986a).

In conclusion, there is evidence that applications of FYM and N fertiliser have an influence on N best management. The growing plants will take up some of the available soil N brought about by the FYM and N fertiliser applied, however the surplus inorganic soil N is at risk to loss. Thus, the concerns should be targeted to the extra amounts of N mineralised exceeding the capacity of the crops to utilize them.

Sommerfeldt, ***et al.*** (1988) suggested that there could be potential problems, depending on the NO_3^--N concentrations and their movement, when the amounts of total N mineralised and nitrified into NO_3^--N from long-term repeated annual FYM applications exceed the crops N requirement.

4.2- IRRIGATION PRACTICES:

Today, irrigation is practiced on some 220 X 10^6 ha in the world, with about 50% of this area in arid and semi-arid regions (Heermann, ***et al.***, 1990a). The usual aim of irrigation is to add water to soil for the purpose of supplying the moisture essential for plant growth. Irrigation in addition affects soil aeration, soil temperature, and nutrient leaching (Hansen, ***et al.***, 1979; Campbell & Campbell, 1982; Trout, ***et al.***, 1990).

This section aims to discuss the relationship between irrigation practices and N in soil and includes the following:

1- Irrigation scheduling versus variations in soil moisture conditions.

2- Leaching requirement versus N losses.

3- Water use efficiency versus N use efficiency.

4.2.1- Irrigation scheduling versus variations in soil moisture conditions:

Irrigation scheduling is a decision-making process repeated several times a year. It determines when to irrigate and how much water to apply (Hansen, ***et al.***, 1979; James, 1988; Martin, ***et al.***, 1990). In principle, irrigation scheduling is determined on the basis of monitoring the soil, the crop and/or the climate (Haise & Hagan, 1967; Campbell & Campbell, 1982; Fair, ***et al.***, 1983; James, 1988; Bucks, ***et al.***, 1990; Heermann, ***et al.***, 1990b; Martin, ***et al.***, 1990).

Irrigation scheduling on the basis of soil monitoring is probably the oldest method in existence and still the most popular of the methods (Campbell & Campbell, 1982; Fair, ***et al.***, 1983). This method is based on observing the depletion in the amounts of soil water available to plants measured from field capacity (FC). The available water is the amount of water between the field capacity (FC) and permanent wilting point (PWP) (Haise & Hagan, 1967; James, 1988; Martin, ***et al.***, 1990). The FC (soil matric

potential of -10 to -33 kPa) is defined as the soil water content at which drainage becomes negligible and is the maximum water content for irrigation. The PWP (soil matric potential of -1.5 MPa) is the lowest limit of water that plants can remove from the soil.

The goal of scheduling by the soil monitoring method is to allow the depletion of available water to a limit that does not cause yield reduction (Heermann, ***et al.***, 1990b; Martin, ***et al.***, 1990). Soil type, rooting depth, crop sensitivity to stress, time of the season, and characteristics of the irrigation system are among the factors determining the depletion limit (Martin, ***et al.***, 1990). For many crops, different investigators have assumed that 50% of the available water holding capacity in the root zone depth can be allowed to deplete before each irrigation without an effect on crop yield (Hansen, ***et al.***, 1979; Withers & Vipond, 1980; Heermann, ***et al.***, 1990b; Martin, ***et al.***, 1990).

For different soil textures the 50% allowable depletion limit takes place at different soil matric potentials. Figure 1.5 illustrates the relationship between the soil matric potential and the percentage of available water depletion (Martin, ***et al.***, 1990).

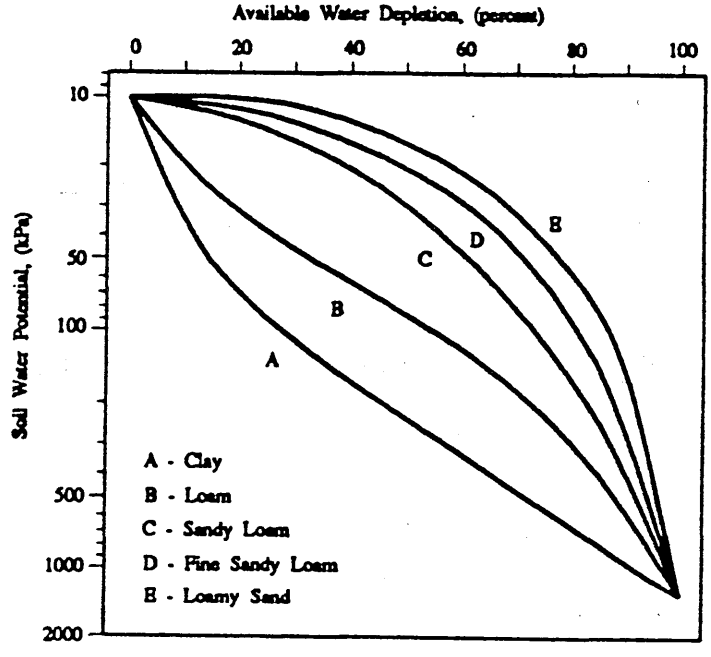


Figure 1.5. The relationship between the soil matric potential and available water depletion (Martin, ***et al.***, 1990).

James (1988) indicated that the potential rate of transpiration (i.e., the transpiration rate that occurs when the stomata are fully open) can cause considerable variations in the water content at the available water depletion limit. Taylor (1965) and Hagan & Stewart (1972) produced tables showing the matric potentials at which water should be applied for maximum yields of various crops.

This shows that differences in the amounts of water needed to be applied to soil occur not only as results of crop varieties or climate (Doorenbos & Pruitt, 1977), but also of the different soil textures. This suggests that different amounts of water will be applied to soils at different timings (irrigation frequencies). Accordingly, variations in the soil moisture conditions caused by the different amounts of water applied are likely.

Variations in the moisture conditions occur due to the irrigation frequency and the method of irrigation (i.e., surface irrigation, sprinkler irrigation, and trickle or drip irrigation). In surface irrigation, for instance, water is applied at low frequency irrigation (i.e., 10 to 14 days) and in large depths. Such irrigation scheduling allows the moisture conditions to oscillate between the FC and the maximum allowable depletion limit (Heermann, ***et al.***, 1990b). In contrast, sprinklers (e.g., center pivot) are managed to apply water at high frequency (i.e., 1 to 7 days), maintaining relatively high soil water contents in the upper root zone, where plant nutrients are usually in great supply (James, 1988; Campbell & Campbell 1982; Bucks, ***et al.***, 1990; Martin, ***et al.***, 1990).

Also, the moisture conditions may be varied due to the performance of irrigation systems. Different methods of irrigation have different efficiencies (Hansen, ***et al.***, 1979; James, 1988; Kruse, ***et al.***, 1990). The efficiencies might be: water application efficiency (i.e., the capability of irrigation system to store the applied water in the soil root zone where it is available to plants), the storage efficiency (i.e., the capability of the system to replace all the soil water deficit in the soil root zone), and uniformity coefficient (i.e., the capability of the system to apply water uniformly to all parts of an irrigated field). For example, application efficiency for surface irrigation often appears to be low compared to sprinkler (i.e., 0.75 or more) or trickle irrigation (i.e., 0.90 to 0.95). This suggests that variations in the moisture conditions are likely to be observed in irrigated fields using different irrigation methods or the same method.

This leads us to conclude that variations in the moisture conditions are possible in fields under irrigation. The variations in the moisture conditions will cause differences in the microbial activity and N transformation processes (Already discussed, see Section 3.2.2).

4.2.2- Leaching requirement versus N losses:

Rhoades & Loveday (1990) indicated that throughout the world most major irrigation schemes (i.e., about 50% of all existing irrigation areas) are affected to some degree by salinity and waterlogging, and many once-productive areas have become saline wastelands (i.e., 10 X 10^6 ha of irrigated land abandoned annually). This is because irrigation waters contain some salt which is not taken up by crop and so concentrates in the root zone whilst the water is transpired.

Rhoades & Loveday (1990) suggested that a prime requirement for salinity control in irrigation projects is that leaching and natural or artificial drainage be adequate to ensure that the net flux of water (and salt) in the root zone is downward, providing the water table is deep enough to allow adequate root development, aeration, and trafficability.

Thus, during irrigation, extra water on top of crop water demand (i.e., evapo-transpiration, ET) should be applied to satisfy the leaching requirement (LR). Heermann, ***et al.*** (1990a) suggested that a small percentage of the water applied to crops should move downward below the root zone to remove the salts, which would otherwise accumulate in the root zone. Bohn, ***et al.*** (1985) indicated that the most common approach to salinity management is to maintain an appropriate leaching requirement (LR), defined as:

$$LR = EC_i / EC_d$$

where EC_i and EC_d are the EC values of irrigation and drainage water (dS m^{-1}), respectively. This extra water however is expected to leach all water soluble constituents. Wagenet (1983) states the water soluble salts as well as fertilisers, soil amendments, and organic and inorganic wastes are all subject to displacement once applied to the soil surface.

N leaches from the soil root zone mainly in the form of NO_3^--N, its movement being closely related to water movement (Legg & Meisinger, 1982). The amount of NO_3^--N leaching from the root zone is a function of soil characteristics, irrigation management, and applications of N fertiliser (Broadbent & Carlton, 1978; Hanks, ***et al.***, 1983; Pratt, 1984; Martin, ***et al.***, 1991; Smith & Cassel, 1991; Williams & Kissel, 1991; Miller & Anderson, 1994).

Meisinger & Randall (1991) state that estimates of NO_3^--N leaching losses commonly range between 5 and 50% of the total N applied, being a major pathway of N loss in humid region agriculture and under irrigation. Under irrigation, it is attributable to inefficient irrigation management. On irrigated lands, over-irrigation (or the practice of applying more irrigation water than soil can store) and non-uniform distribution of irrigation water caused by poor system design (and/or wind conditions) are among the probable causes for high NO_3^--N percolation rates (Dylla, ***et al.***, 1976). Under non-uniform irrigation, Pang, ***et al.*** (1997) suggested that it is impossible to manage either water or N application in a manner to achieve high yields without considerable NO_3^--N leaching.

According to Hanks, ***et al.*** (1983), it is common irrigation experience to observe N-deficient crops under excessive irrigation practice, this result being explained by the leaching losses of NO_3^--N from the root zone. On sandy soils in Washington, Middleton, ***et al.*** (1975), quoted by Hanks, ***et al.*** (1983), found that the yield of potatoes was less than the maximum with N fertiliser rates as high as 446 kg ha^{-1} under the furrow method of irrigation. Where the sprinkler method was used, with frequency and amount tied to ET demand, the yield was as high as those obtained on loam soils fertilized with 180 to 360 kg N ha^{-1}. Furrow irrigation required about twice as much water as sprinklers.

Biggar and Nielsen (1967) indicated that intermittent sprinkling (0.03 to 0.51 cm hr^{-1}) reduced the salt content of the upper 2 ft (0.61 m) to the same degree using less water than the continuous ponding (0.51 to 5.49 cm hr^{-1}). The amounts of water applied by the two methods were 26 and 75 cm, respectively. Biggar and Nielsen (1967) concluded that the slower flow rate which allows more time for diffusion

combined with the unsaturated flow accounts for the difference in leaching characteristics under the two methods.

This suggests that the pattern of NO_3^--N distribution in and leaching out the root zone will be different under the various methods of irrigation, agreeing with the findings of different investigators (e.g., Viets, ***et al.***, 1967; Legg & Meisinger, 1982; Bingham, ***et al.***, 1988; McConnell, ***et al.***, 1996).

Nonetheless, the relative performance of irrigation systems also depends on the crop and the type of soil, which complicates the comparison of N leaching losses under different systems. Therefore, to study N leaching under irrigation system(s), Viets, ***et al.*** (1967) suggested that attention ought to be given to the soil water suction and its uniformity in the root zone, the rate of fertilizer application and its movement in the soil water, and the effect of the soil water regime on mineralisation of nutrients from the soil. These factors modify the growth of irrigated crops varying crop N uptake, after which the leaching losses of N and its distribution in the root zone would pose a risk.

Broadbent & Carlton (1978) and Pratt (1984) suggested that the quantity of fertiliser N percolating below the root zone is likely to be minimal when the crop requirement for N is not greatly exceeded. It should be emphasized that high yields and low NO_3^--N leaching irrigation are compatible goals and can be achieved by appropriate irrigation and fertiliser management (Broadbent & Carlton, 1978; Pang, ***et al.***, 1997).

It is possible to conclude from the discussion of this section that good management of irrigation and N supply can reduce the losses of NO_3^--N by leaching from the root zone. The control of irrigation amounts to minimise the deep percolation rates should be the goal of irrigation management. This can be achieved by improving the performance of the irrigation system and the plan of irrigation scheduling. The management of N supply should aim to meet the crop N demand, reducing the surplus of N in the root zone. All the N sources and the time, quantity, and method of application should be accounted for to secure the best management of N supply.

4.2.3- Water use efficiency (WUE) versus N use efficiency (NUE):

Water use efficiency (WUE) is defined as the grain yield divided by the total water applied (i.e., kg per ha-cm) (Rhoads, 1984). N use efficiency (NUE) is also defined as the percentage of N fertiliser recovery in the above ground plant parts (Bock, 1984).

Important interrelationships between WUE and NUE on crop yield have been observed (Brown, 1971; Black, 1981; Hanks, ***et al.***, 1983; Rhoads, 1984; Reichman, ***et al.***, 1986; Hussain & Al-Jaloud, 1995; Pala, ***et al.***, 1996; Pang, ***et al.***, 1997). An example of these interrelations between water application, N fertilisation, and the yield of winter wheat is outlined in Table 1.2 (Rhoads, 1984).

Table 1.2. The interrelationships between water application, N fertilisation, and the yield of winter wheat (Rhoads, 1984).

Water applied		N applied (kg h^{-1})			
Rainfall	Irrigation	0	22	45	90
(cm)		WUE (kg per ha-cm)			
31	0	43	63	71	71
31	7.4	60	87	110	124
31	20.6	62	91	115	133

Table 1.2 shows that the highest grain yield per centimetre of water used (133 kg ha^{-1} cm^{-1}) was produced under the highest levels of available water and N rate (90 kg N ha^{-1}). However, under the lowest available water level the maximum WUE occurred at the N application rate of 45 kg ha^{-1}.

Black (1981) indicated that N fertilisation promotes the crop yields in years with ample rainfall but not in dry years and vice versa, which suggests that the WUE is increased by the N fertilisation, and that the efficiency of the N use is increased by water supply.

In a series of researcher-managed wheat fertiliser trials undertaken between 1986 and 1990 on representative rainfed fields across northwest Syria, Pala, ***et al.*** (1996) found that wheat yields (grain and straw) were correlated (r^2 = 0.65) with seasonal rainfall (250, 350, and 450 mm), with a highly significant (P = 0.001) response to N

fertiliser (0, 40, 80, and 120 kg N ha^{-1} as NH_4NO_3) which increased with increasing rainfall and decreasing initial soil mineral-N values.

Also, it was shown that water application improves dry matter yield (DM) response to N fertilisation (kg DM /kg N/ha) (Rhoads, 1984). Comparing the grain yields of field corn fertilized with 336 kg N ha^{-1} under no irrigation and irrigation with high frequency, Rhoads & Stanley (1973) reported that the yields increased from 7200 kg ha^{-1} to 11900 kg ha^{-1}, respectively. Irrigation was repeated 11 times when the soil-water suction at the 15 cm depth reached 0.20 bar. For both irrigation treatments, the ratio of grain yield divided by amounts of N applied was 21.5 and 35.5 kg DM /kg N/ ha, respectively.

This interrelationship between WUE and NUE on crop yield, however, occurs under certain water regimes and amounts of applied N. Pala, ***et al.*** (1996) indicated that there was no response to N applied when rainfall was less than 250 mm, but 40 and 80 kg N ha^{-1} were needed for optimum wheat grain production when rainfall reached to 350 and 450 mm, respectively.

Brown (1971) reported that WUE was 73, 114, and 115 kg per ha-cm with 0, 67, and 268 kg N ha^{-1}, respectively. The total ET also increased from 22 cm with no N applied to 32 cm with the application of 268 kg N ha^{-1}. Pang, ***et al.*** (1997) indicated that increasing N application increased the amount of applied water above which yields decreased. As well, Pang, ***et al.*** (1997) observed that the higher water applications reducing yields were associated with higher NO_3^--N leaching for a given N application.

This shows that there are interrelationships between irrigation and N fertilisation on crop yield, which suggests that both N and water applications require careful attention to avoid excessive N leaching losses. Keeney & Follett (1991) suggested that improvement in irrigation WUE with new technologies and water needs forecasting can be expected as water costs rise. These approaches will also improve the efficiency of N use by reducing the amount of NO_3^--N leached.

In conclusion, it has been shown that application of FYM, N fertilisers, and irrigation practices influence the losses of N by leaching. To promote maximum crop production and least environmental impacts, these losses might be minimised by a proper management of soil water, irrigation practice, and N fertiliser.

5- EXCESS OF N AND ITS IMPACTS ON NATURAL RESOURCES.

Excess N in soil causes an antagonistic impact on environment and natural resources, and hence on man-kind, livestock, and ecology. Table 1.3 outlines the types of contamination, forms of N contaminants, and the unwanted consequences, resulting from agricultural activity (Conway & Pretty, 1991).

Table 1.3. Types of contamination, forms of N contaminants, and the consequences resulting from agricultural origin (Conway & Pretty, 1991).

Types	Forms	Consequences
Water	N species including NH_4^+, NO_2^-, NO_3^-.	Health problems: methaemoglobinaemia in infant; possible cause of cancer. Algal growth and eutrophication: causing taste problem, surface water obstruction, fish kills, coral reef destruction, and illness due to algal toxins.
	Organic livestock wastes	Algal growth, plus deoxygenation of water, and fish kills.
Food and Fodder	NO_3^-	Increased nitrates in food, methaemoglob-inaemia in livestock.
Farm and Natural Environment	NO_3^-	Harm to plant communities.
	NH_3 from livestock and paddy fields	Disruption of plant communities, possible role in tree deaths.
Atmosphere	NH_3 from livestock manures and paddy fields	Odour nuisance; plays role in acid rain production.
	Nitrous oxide (N_2O) from fertilisers	Plays role in ozone layer depletion and global climatic change.

Emission of nitrogen oxides (NO_x) and ammonia (NH_3) and their transformation products may cause a wide range of environmental consequences at local, national, or global level such as: acidification, eutrophication, and the formation of tropospheric

ozone, contributing to greenhouse gases and climate change through radiative forcing (DOE, 1994).

Wayne (1993) indicated that N gas and its compounds play a major part in atmospheric chemistry. Among the most important compounds are the nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), ammonia (NH_3), organic nitrate (peroxyacetyl nitrate, PAN, $CH_3CO.O_2NO_2$), and the nitrate radical (NO_3). These affect the atmospheric chemistry in different ways. Both NO and NO_2 demolish the ozone layer in the stratosphere, and they are the precursor of nitrous acid (HNO_2) and nitric acid (HNO_3). N_2O and NH_3 play a major role in the physics of the Earth's atmosphere by contributing to so-called 'greenhouse' heating which influences the surface temperature and so the climate. The free radical NO_3 enters various reactions contributing to acidification via the formation of HNO_3.

Another environmental major concern is the loss of NO_3^--N by leaching. Different investigators (e.g., Addiscott, ***et al.***, 1991; Hill, 1991; Black, 1993) indicated that high concentrations of NO_3^--N in drinking water may cause methemoglobinemia and stomach cancer. Methemoglobinemia is the occurrence of methemoglobine in blood, which is a form of hemoglobin with the normal form of iron (i.e., ferrous, Fe^{2+}) is reduced to ferric (Fe^{3+}). This causes O_2 to be tightly held, retarding the alternating process of oxygenation and de-oxygenation involved in O_2 transport from lungs to tissues (Hill, 1991; Black, 1993).

Addiscott, ***et al.*** (1991) outlined some cases of methemoglobinemia connected with high concentrations of NO_3^--N in drinking water from different countries at different periods (Table 1.4).

The health hazards attributed to NO_3^--N in drinking water have led different organizations to initiate maximum limits on NO_3^--N concentrations in water used for drinking purposes. Table 1.5 summarises some of these limits with the corresponding organization (Oakes, 1991).

Table 1.4. Some cases of methemoglobinemia attributed to high concentrations of NO_3^- (mg NO_3^- l^{-1}) in drinking water (Addiscott, ***et al.***, 1991).

Reporter	Year	Country	Cases	mg NO_3^- l^{-1}
Comly, H. H.	1945	USA	2	388, 619
Ewing, M. C. & Mayon-White, R. M.	1951	UK	2	200, 95
Choquette, K.	1980	USA	1	1200
Busch, D. & Meyer, M.	1982	USA	1	545
Acheson, E. D. C.	1985	UK	14	> 100
Deak, S.	1985	Hungary	95 1258	40-100 > 100
Hye-Knudsen, P.	1985	Denmark	1	200
Johnson, C. J. & others	1987	USA	1	665

Table 1.5. Limits of nitrate (NO_3^-) concentrations in drinking water (Oakes, 1991).

Organization	Year	Nitrate status	Nitrate limit (mg NO_3^- l^{-1})
WHO European Standard	1970	Recommended Acceptable Unrecommended	<50 50-100 >100
WHO International	1971		45
WHO Working Group Recommendation: A- General Population: B- Infants (below 6 months):	1977	 Acceptable Borderline Unacceptable Unacceptable	 <50 50-100 >100 >50
US Environmental Protection Agency	1977	Maximum	45
Health and Welfare, Canada	1978	Max. Acceptable	45
EEC (Directive on quality of surface waters intended for abstraction of drinking water)	1980	 Max. Admissible Guide Level	 50 25
WHO Guide-lines on Water Quality	1984	Guide Value	45

As a conclusion to this section, it should be emphasized that N losses are not only of economic interest. It was shown that N losses cause adverse effects on the environment and natural resources, which suggests that adequate attention should also be given to the possible environmental damage by these losses. In areas where water resources are limited, the loss of NO_3^--N by leaching demands particular considerations to avoid deteriorating the quality of water.

6- THE AIMS AND OBJECTIVES OF THE STUDY:

This study involves experiments using pots and leaching columns under different wetting regimes. The experiments have been undertaken in a controlled temperature environment at 20°C. The aim and objectives of this study are as follows:

6.1- AIM

The general aim of this study is to investigate the loss of NO_3^--N by leaching resulting from agricultural practices, involving applications of N in the form of FYM and N fertiliser under a simulated center pivot irrigation in a relatively warm and dry climate.

6.2- OBJECTIVES:

1- To study the effects of intermittent wetting-drying conditions on microbial N release from different rates of FYM applications.

2- To examine the effects of N fertiliser application on microbial N transformation from the FYM applied under different moisture conditions.

3- To investigate the effects of simulated irrigation practices on leaching losses of NO_3^--N transformed from the applied FYM.

CHAPTER TWO

AGRICULTURE IN THE KINGDOM OF SAUDI ARABIA (KSA).

The aim of this chapter is to give a general background about agricultural progress in the Kingdom of Saudi Arabia (KSA). The chapter starts with a general discussion concerning the country and concludes with the agricultural progress achieved and nitrogen (N) fertiliser use in the KSA. The discussion is concluded as follows:

1- Location and area.
2- Geological features.
3- Structural features.
4- Climate.
5- Soil properties.
6- Ground water.
7- Agricultural progress.
8- Preliminary N budget.

1- LOCATION AND LAND AREA.

The KSA is a vast country with a total land area of 2.2 X 10^6 km^2 (about 8.5 X 10^5 square miles), covering 80% of the Arabian Peninsula. The KSA is located in the southwest of Asia between longitudes 35° and 56°E and latitudes 16° and 32°N (EL-Khatib, 1974; AL-Gasham, 1989).

2- GEOLOGICAL FEATURES.

Chapman (1978) indicated that the Arabian Peninsula is a huge crustal plate made up of ancient sedimentary and volcanic rocks, which are deformed, metamorphosed, and injected by plutonic intrusions. Today, the Peninsula is divided into two territories (Figure 2.1): a western territory (the Arabian Shield) and an eastern territory (the Arabian Shelf). The description of these geological features is summarised as follows.

2.1- THE ARABIAN SHIELD:

The Arabian Shield is an ancient land mass, which is a part of the Precambrian crustal plate, generally exposed but locally covered by Tertiary volcanic rocks. The Shield occupies a trapezoidal area of about 7.7 X 10^5 km^2 in the western part of the Peninsula along the Red Sea.

The Shield has a relatively smooth and slightly-arched surface, which is a peneplain now sloping very gently toward the north, northeast, and east under a thin sedimentary cover in eastern Arabia. Its framework consists of Precambrian gensis and

metamorphosed sedimentary and volcanic rocks, which were folded and faulted in two major orogenies (Al-Hijaz and Najd) and intruded by granites. The surface was covered, in part at least, by lower Paleozoic basal sands in late Precambrian time following peneplanation. In the Tertiary, great floods of basic lava poured out onto the surface.

2.2- THE ARABIAN SHELF:

The Arabian Shelf lies to the east of the Shield, where it forms about two thirds of the Peninsula. It consists of a thick sedimentary sequence covering the plate. Its foundation is a part of the same Precambrian plate making up the Shield.

On this rigid peneplaned basement lies a sequence of continental and shallow-water marine sedimentary rocks, ranging in age from Cambrian to Pliocene. They dip gently away from the Shield and into a number of deep sedimentary basins.

The Shelf can be divided into three subprovinces: Interior Homocline (characterized by dips ranging from about one degree in the older units to less than half a degree in the Upper Cretaceous and Eocene beds), Interior Platform (a very broad area of low relief in the east of the Homocline), and sedimentary basins (i.e., Al-Rub Al-Khali (the Empty Quarter), Al-Dibdibah, Northern Arabian Gulf, and Al-Sirhan-Turyf).

3- STRUCTURE FEATURES.

The structure of the KSA is divided into three major features (Burrell, 1976). They are as follows:

3.1- THE WESTERN COAST LAND AND MOUNTAIN FRINGES:

These are formed of relatively high escarpments, which run parallel to the Red Sea and enclose a narrow coastal plain. This region is best subdivided into tow parts: the Hijaz and the Asir to the north and south of Makka, respectively.

The Hijaz is low in overall altitude ranging from 608 to 2128 m (2,000 ft to 7,000 ft). The Asir exceeds 2432 m (8,000 ft) and rises to over 3648 m (12,000 ft) in its southern extension in Yemen.

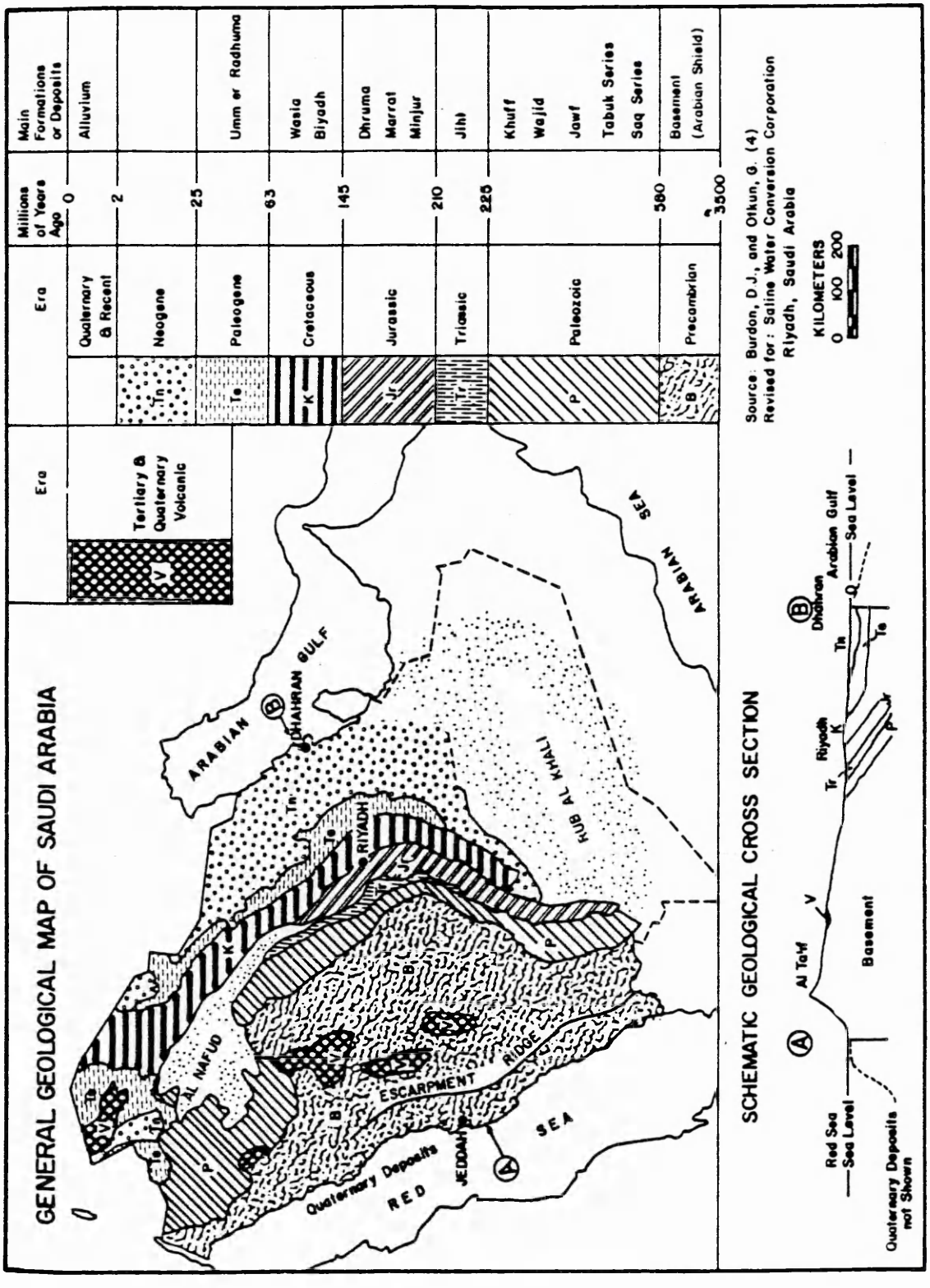


Figure 2.1. The general geological map of the KSA (Caro & Eagleson, 1981)

The Asir highlands receive the highest rainfall rates of the country due to their exposure to the monsoon of the southwest of the Indian Ocean. This monsoon has created a series of alluvial plains.

3.2- THE CENTRAL DESERTS PLATEAU:

This lies east of the western escarpments sloping down to the east. In the east of this region, there is Najd (the heart of the country), which is an area of rock and low isolated ridges. Some escarpments (the Tuwaiq) are located in this region, ranging in altitude between 2 and 243 m (6 ft to 800 ft). Several wadis (i.e., valleys) extend eastward from the watershed of the Hijaz and the Asir. The most important ones are the Dawaser, Rumma, and Surra.

There are also several oases, scattered in this region. Among them are Burrayda, Unayza, Riyadh, Khrj, and Aflag in the eastern part of Najd and Hail in the north. Between the oases, there are major grazing areas.

To the north of Najd, there is the Great Nafud desert (i.e., a southern extension of Syrian desert), which contains scattered oases and marginal winter rainfall producing vegetation for long winter and spring grazing. Al-Dahna desert, which provides some winter and spring pasture, but to a lesser extent than the Great Nafud. The Rub Al-Khali (i.e., the Empty Quarter), that grows some seasonal grasses. Both Al-Dahna and the Rub Al-Khali deserts are located at the east and south borders of Najd, respectively.

3.3- THE FLAT LOW LANDS OF THE EASTERN COAST:

The eastern coastal belt of the country contains the country's largest oases complex. Some of the oases located in this region include Hassa (i.e., probably the largest oasis of the country, extending over an area of 20,000 ha), Qatif (an oasis laying next to the Arabian Gulf), and Jibrin (in the south of the region).

4- THE CLIMATIC CONDITIONS.

The Kingdom of Saudi Arabia is classified as an arid country, and possibly considered the driest country in the world. It occupies nearly 5% of the global arid lands (AL-Gasham, 1989).

The climatic conditions in the KSA display a wide range of variation in their values between the different locations and regions. However, the averages are used here for simplicity. The climatic values discussed here are summarised from Ministry of Agriculture and Water (MAW) (1984), unless other wise stated. The discussion is concluded as follows:

1- Solar radiation and sun shine.
2- Temperature.
3- Wind.
4- Rainfall.
5- Relative humidity.
6- Evaporation.

4.1- SOLAR RADIATION (SR) AND SUNSHINE DURATION

The distribution of solar radiation (SR) in the central inland and eastern inland regions of the Kingdom is generally uniform. In the west, seasonal clouds (especially during summer) decrease the potential radiation levels. Dust storms may attenuate radiation energy levels along the Tihama plain (southwest) and in the regions of the central and eastern inland.

A 5-years investigation of monthly SR at selected locations around the Kingdom demonstrated that the mean monthly maximum SR is about 600 langleys a day (a langley is a unit of solar radiation equivalent to one gm calorie per cm) between the months of June and July. In the southwest, the seasonal maximum levels of SR are reached during early summer, but later in the summer clouds lower the levels of radiation.

The average sunshine hours in a particular month could be consistently less than the maximum possible. This is because of cloud cover from seasonal weather systems moving across the country. The range of seasonal sunshine hours in the KSA is between 6 hours during the winter and 12 hours during the summer.

4.2- TEMPERATURE:

The ambient air temperature in the KSA varies greatly from season to season and from region to region. The maximum temperature occurs in July, and the minimum is in January. The seasonal average temperature is 34°C in summer (June, July, and August) and 14°C in winter (December, January, and February), with a wide range of variations between the two seasons (AL-Gasham, 1989).

The Kingdom can be divided into different temperature regions as follows: northern, eastern-central interior, west-central interior and the Asir high land, and the coastal region. Each region has recorded a range of temperature from 0°C or below in the winter to more than 48°C during the summer. Nonetheless each region has its own characteristic pattern of temperature. Table 2.1 outlines the ranges of summer and winter mean temperature for various stations located in different regions of the country.

Table 2.1. The ranges of seasonal temperature in different regions of the KSA (MAW, 1984).

The region	The seasonal range of temperature(°C).	
	Summer	Winter
Inland	28-39	5-20
Arabian Gulf	31-37	11-22
Red Sea	28-34	19-27

During the winter season, temperatures below freezing are not uncommon in the northern and central inland regions. In other parts though they are less common. The exception is for the coastal areas where winter temperatures are higher than inland.

In the summer, temperature may exceed 48°C throughout the inland areas. Coastal regions rarely experience such high temperatures. Throughout the Kingdom, very high temperatures combined with extreme diurnal and annual variations often occur. The diurnal range of temperature (i.e., difference between the highest and the lowest) may exceed 20°C in inland regions. Along the coast, it is less than 15°C.

4.3- WIND:

The annual average wind in the KSA is between 5 and 15 km hr^{-1}. During the winter months, there are strongly variable winds associated with storms. The strongest and most persistent winds in the country are usually recorded in February. As spring months (March, April, and May) approach these persistent and strong winds lessen in frequency. However, localized strong winds continue to be present in the vicinity of thunderstorms. Generally throughout the Kingdom, the most frequent prevailing wind direction in these seasons is from the west to northwest.

With the onset of summer and the resultant heating of the KSA land mass, a stationary low pressure system develops over the Asian Continent. The southwestern part of this low pressure system engulfs the eastern coast of the KSA, causing more persistent north to northwest winds. By mid-summer, frequently strong northerly winds called "shamal" occur in which gusts of 100 km hr^{-1} have been recorded, with blowing dust and sand reducing visibility. These winds weaken by the end of July, and the least amount of wind is observed in August. Coastal areas experience sea and land breezes through summer due to temperature differences between the surfaces of land and sea.

The autumn months (September, October, and November) experience cooler temperatures and higher relative humidity along with the beginning of the winter storms which bring southerly winds. As the storm fronts pass, the southerly winds shift to the direction of northwest.

4.4- RAINFALL:

Rainfall occurs primarily during the winter and the spring. In some parts of the country, appreciable summer rainfall occurs. The winter and the spring rainfall is caused by a combination of disturbances from the Mediterranean and the Sudan trough, respectively. The winter rainfall occurs in relatively significant amounts in the northern, western, and eastern regions. Spring rainfall occurs in the central and southern regions. Summer rains are mostly restricted to the southern half of the country due to the influence of the southwest monsoon and the Intertropical Convergence Zone.

The annual average rainfall of the country has been reported to be about 95 mm (Othman, 1983; AL-Gasham, 1989). Othman (1983) summarised the annual average rainfall in the different regions of the country (Table 2.2).

Table 2.2. The annual average rainfall for different regions in the KSA (Othman, 1983).

The region	Southwest	Northwest	East and North East	Central
The average (mm)	500	50 to 75	50 to 100	75 to 100

4.5- RELATIVE HUMIDITY (RH):

The lowest relative humidity (RH) in the KSA is generally observed during June and July, whereas the maximum RH is in the months of December and January. Along the coastal areas, the RH is the highest during both January and July. The yearly variation in RH at coastal meteorological stations is low when compared with the variations in inland stations. Table 2.3 shows summer and winter RH for different regions of the KSA.

Table 2.3. The seasonal ranges of relative humidity (RH) in different regions of the KSA (MAW, 1984)

The region	The ranges of RH (%).	
	Summer	Winter
Inland	13-47	35-78
Arabian Gulf	37-63	65-73
Red Sea:		
Jeddah & Jizan	59	61
Wajh	74	53-57

4.6- EVAPORATION:

The meteorological stations of the Ministry of Agriculture and Water throughout the KSA are equipped with the Standard US National Weather Service Class A pans for the measurement of daily evaporation rate.

Several studies have been conducted on evaporation in various areas of the Kingdom . In the west, studies indicate that evaporation is low along the coastal lands. It remains low as one moves to the higher elevations along the escarpment, but increases eastward in the interior. The magnitude differs considerably ranging from annual totals of 2000 mm at Abha (southwest highlands from 2100 to 2600 m) to 3000 mm at Sulayyil (an interior south). The maximum monthly evaporation reported was 191 mm in Abha and 330 mm at Sulayyil during July. The minimum monthly evaporation at Abha and Sulayyil occurred during December (i.e., values of 106 and 140 mm, respectively).

In the central part of the Kingdom, the dominant climatic features are high temperature, low RH, and hot advective winds. The combination of these features results in high evaporation rate. An annual evaporation rate of 3126 mm has been recorded in Kharj (south of Riyadh).

Along the Arabia Gulf coast, evaporation rates are low. At Qatif for instance the evaporation rates are among the lowest in the country. Different climatic values for the major agricultural regions in the KSA are summarised in Appendix A-2.1 (Transworld, 1992). Averages of these values are also included in Appendix A-2.1.

These variations in the climatic features cause considerable differences between the values of reference evapotranspiration (ET_o) estimated using the modified Penman equation for the different regions of the KSA. For instance, AL-Zeid, ***et al.*** (1988) indicated that the ET_o value for Hassa (an area characterised by deserts) is 2472 mm. For Madinah (coastal mountainous hot and dry in the west) ET_o is 3190 mm, and for Najran (mountainous cool and dry in the southwest) the value is 2083 mm. AL-Zeid, ***et al.*** (1988) also estimated water requirements for the major commercial crops grown in different regions of the Kingdom on basis of the climatic features.

It is possible to conclude that the climatic features of the KSA demonstrate the aridity of the country, suggesting the need for irrigation practices to sustain agricultural production. Irrigation water comes primarily from scarce water resources (as will be discussed later in this Chapter), which caused authorities to encourage farmers to adopt advanced irrigation technology (i.e., centre pivot systems). Also, attention needs to be given to the environmental damage that is possible from the loss of NO_3^--N by leaching under irrigation (Section 5, Chapter One).

5- SOIL CHARACTERISTICS.

More than one third of the surface area of the KSA is covered by deserts consisting of high sand dunes which are not stable (MAW, 1995). The soils of these dunes are classified as Torripsamments/ Calcaric Arenosols. Though small isolated areas of these soils are likely to be found in every region, they are extentsive in Rub Al-Khali, Al-Nafud, and Al-Dahna. On both eastern and western coasts, narrow strips of the beaches also have sandy soils, which remain wet due to tidal sweeps and high water table. These are classified as Udipsamments/ Gleyic Arenosols. The soil associations, extent, and main characteristics of soils in the KSA are summarised in Appendix A-2.2 (MAW, 1995).

MAW (1995) indicated that most soils of the KSA are young, as they have not had much pedogenic development due to the dearth of moisture and continual renewal of the surface by erosion and deposition. However, in small areas scattered over the country, soils with genetic horizons can be found and could be therefore considered as relatively old. Because there is not enough rainfall to leach out the carbonates, all soils are calcareous, being classified as Calciorthids/ Haplic Calcisols. The contents of calcium carbonates ($CaCO_3$) are high, ranging between 5 and 15%.

According to the General Soil Map of the KSA prepared by the Department of Land Resources (MAW, 1985), the main soil orders in the KSA are Entisols, Inceptisols, and Aridisols. The dominant properties of soils in the KSA are coarse texture, low organic matter (less than 1%), low available N and phosphorus (P), and a moderate content of potassium (K). Salinity forms a major problem in different regions of the country.

These dominant properties of soils in the KSA were also reported in works undertaken in different regions by various investigators (AL-Arini, ***et al.***, 1973; Mashhady & Omar, 1979; Bashour, ***et al.***, 1983; Shadfan & Hussen, 1987; AL-Barrak, 1985 & 1986; AL-Barrak & AL-Badawi, 1988, Ismaiel, 1989). AL-Jaloud & AL-Shankitti (1992) summarised some of the soil physical and chemical properties of the major agricultural areas in the KSA (Table 2.4).

Table 2.4. The soil physical and chemical properties of some major agricultural areas in the KSA (AL-Jaloud & AL-Shankitti, 1992).

Location	Region	EC	pH	$CaCO_3$	P	K	Textural
		dSm^{-1}		%	mg l^{-1}		class
Hail (HADCO)	north	3.32	7.7	8.5	8.65	156	sandy loam
Tabuk (TADCO)	north	2.00	8.0	6.6	13.50	313	sandy loam
NADEC Farms:							
Harad	southeast	1.75	8.9	13.6	1.30	20	loamy sand
Jouf	north	5.20	8.7	7.0	0.85	565	loamy sand
Kharj	central	2.70	7.7	21.2	5.80	241	sandy loam
Al-Badaeh	central	10.80	7.5	14.0	3.50	241	sandy loam
Hofuf	east	16.30	7.7	16.8	4.10	310	sandy loam
Sulayyil	south	5.50	8.4	7.9	4.60	112	sand

N.B.: HADCO is Hail Agricultural Development Co., TADCO is Tabuk Agricultural Development Co., and NADEC is National Agricultural Development Co.

The mineralogical studies of soils in the KSA showed that soil particles are dominated by different minerals in the different regions (Shadfan, ***et al.***, 1984). Sand and silt particles are dominated by carbonate, quartz, and gypsum in the eastern region. In the central region, they are dominated by quartz, carbonate, and feldspars. Quartz, feldspars, hornblende, and mica are the dominant minerals in sand and silts in the west. The clay fractions are dominated by palygorskite in the east, kaolinite in the centre, and kaolinite, smectite, and mica in the west (Shadfan, ***et al.***, 1984).

Viani, ***et al.*** (1983) reported that the calcareous soils of central basins (Wadi Dawasir and Najran, south and southwest of Riyadh, respectively) have clay fractions in which smectite > mica > kaolinite > chlorite, palygorskite, vermiculite. The clay particles in the basins have greater smectite contents than those of the kaolinitic western highland soils and palygorskitic-rich soils in the eastern region.

Different investigators have observed the predominance of palygorskite in soils of Hassa (eastern region) (Aba-Husayn & Sayegh, 1977; Elprince, ***et al.***, 1979; Shadfan & Mashhady, 1985). Lee, ***et al.*** (1983) indicated that the mineralogical composition of the soils in Qatif is dominated by gypsum or calcite, and smectite is the dominant clay mineral. In Harad (southeast), palygorskite and smectite are the dominant layer silicate minerals.

Clay fractions mainly contain palygorskite and smectite in Gassim area (Mashhady, ***et al.***, 1980; MacKenzie, ***et al.***, 1984), and kaolinite and smectite in Kharj area (Lee, ***et al.***, 1983) (i.e., both are in the central region, northwest and south of Riyadh). AL-Barrak (1985) indicated that the minerals observed in Sawdah (southwest) are kaolinite, illite, smectite and/or intergradient vermiculite, chlorite and quartz. Figure 2.2 shows a schematic presentation of mineralogical composition of soils in the KSA in relation to the geomorphologic pattern across the country (Lee, ***et al.***, 1983).

In conclusion, the discussion shows that soils with similar properties require special considerations in relation to the environmental conditions where they are cultivated. For instance, different investigators (e.g., Ferris, 1953; Farnworth & Robinson, 1972; AL-Noaim & Farnworth, 1972 & 1973; Shadfan & Hussen, 1987; Elsayad, 1988) recommended applications of organic materials (e.g., farm yard manure, FYM) and/or N fertilisers to amend the poor soil fertility conditions. Such practices should take into account the possibility of NO_3^--N loss by leaching, which may degrade the surrounding resources (See also Chapter One).

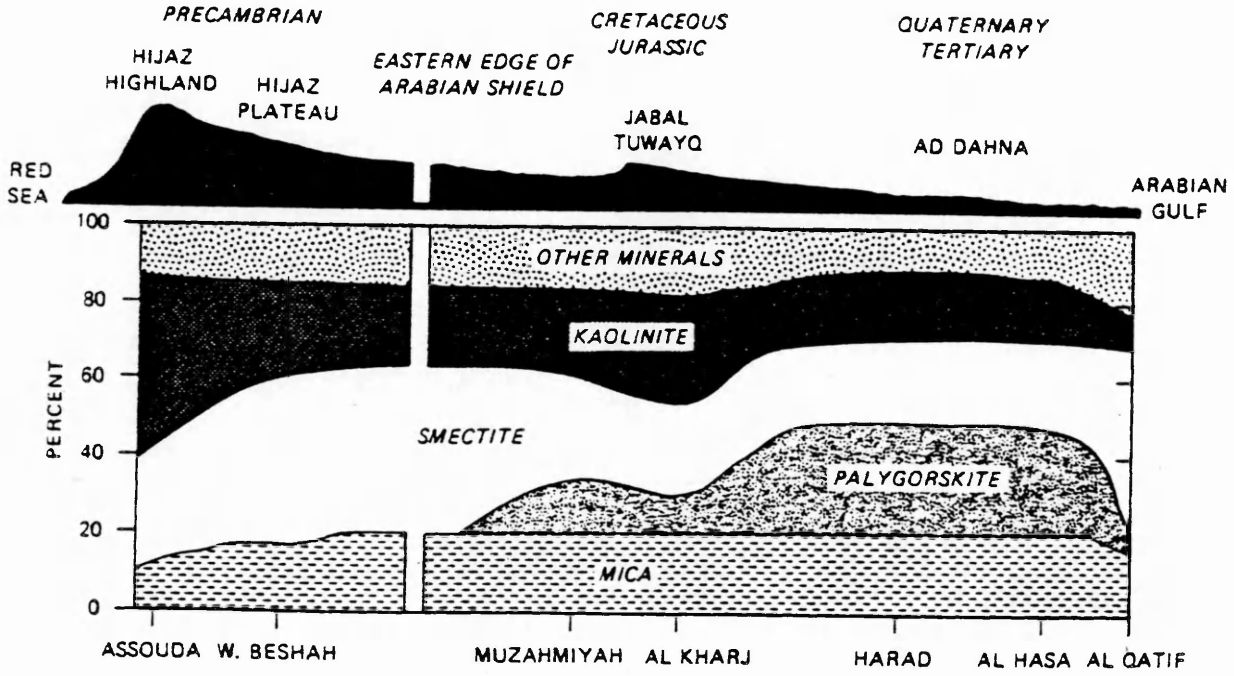


Figure 2.2 A schematic presentation of soil mineralogical composition as related to the geomorphology of the KSA (Lee, ***et al.***, 1983).

6- GROUND WATER:

The KSA is known for its scanty and meagre rainfall, and the lack of reliable and perennial surface waters (i.e., lakes, rivers, or streams). This section aims to discuss the importance of ground water for the country.

For the KSA, ground water is the most valuable water resource. Ground water comes from renewable and non-renewable resources (AL-Ibrahim, 1990 & 1991). The renewable resource is shallow aquifers which contain a renewable water supply recharged by infiltration from rainfall and surface runoff that flows over wadis (i.e., valleys). The non-renewable type is deep aquifers (i.e., depth varies between 100 and 500 m and may exceed 1000 m), which contain reservoirs of water formed during the

last Ice Age (i.e., 15000 to 30000 years ago), when water was trapped in sedimentary rocks (e.g., limestone and sandstone). The renewable water was estimated at about 9.50 X 10^{11} m^3 y^{-1}, whilst estimates for non-renewable water were at 5 X10^{14} m^3.

Deep ground water is reserved in two types of aquifers (i.e., principal and secondary) which are categorized on the basis of their hydrologic properties and areal extent (MAW, 1984 & 1995). Principal aquifers have greater permeability and larger yields than secondary aquifers. AL-Ibrahim (1991) stated that 67% of non-renewable water occurs in the principal aquifers.

MAW (1984) indicated that most prolific aquifers occur in the sedimentary rock strata and underlie two thirds of the Kingdom. The lithologic sequence of these sedimentary rocks has been divided into eight major strata based on the lithology at the outcrop and the position of major un-comformities. The lithology sequence of the aquifers is summarised in Appendix A-2.3 (MAW, 1984).

Though estimated to be relatively of small magnitude, different investigators have indicated that recharge to deep aquifers does take place (Dincer, ***et al.***, 1974a; Dincer, ***et al.***, 1974b; Caro & Eagleson, 1981; Issar & Passchier, 1990; Faulkner, 1994). For the Umm er Radhuma aquifer, Faulkner (1994) indicated that between 1952 and 1978 estimated recharge ranged between 8.3 and 4.08 X 10^9 m^3 y^{-1}, with a mean value of 1.05 X 10^9 m^3 y^{-1}. Issar & Passchier (1990) stated that annual recharge for Wajid and Wasia aquifers was in the order of 1.10 X 10^8 and 2.8 X 10^6 m^3 y^{-1}, respectively.

The British Arabian Advisory Company (BAAC) (1980), quoted by AL-Ibrahim (1991), indicated that annual withdrawals of ground water are far in excess of natural recharge (Table 2.5). This agrees with the findings of Caro & Eagleson (1981) who estimated the recharge from rainfall to be from 20.9 to 50.2 X 10^6 m^3 y^{-1} for Minjur aquifers and from 0.8 to 4.8 X 10^6 m^3 y^{-1} for Wasia aquifers. These values are less than the current amounts extracted (i.e., 79 X 10^6 m^3 y^{-1} and 73 X 10^6 m^3 y^{-1}, respectively). This suggests that ground water is being mined.

Ground water forms the main supplying resource in the KSA as can be seen from Table 2.6 (AL-Ibrahim, 1991). Table 2.6 shows that most of water is supplied by ground water from both renewable and non-renewable (i.e., 77% in 1980 and 84% in 1985). Non-renewable water resources supplied the country with nearly half of the

water required in 1980 and three quarters in 1985. This shows that ground water is of great significance to KSA.

Table 2.5. Estimated water balance for the KSA from 1985 to 2010 (BAAC, 1980).

Year	Estimated recharge	Extraction	Depletion
	X 10^6 m^3		
1985-1990	6 350	32 400	-26 050
1990-2000	12 700	90 000	-77 300
2000-2010	12 700	123 000	-110 300
total	31 750	245 400	-213 650
annual average	1 270	9 816	-8 546

Table 2.6 also shows that most water was consumed by agriculture. In both 1980 and 1985, water used for agriculture was nearly 4 times more than that used for other needs. This explains why authorities in MAW are demanding and encouraging the use of more efficient irrigation systems such as centre pivots.

Part of the water supplied for agriculture is used for salinity control. As stated above (Section 5), soils in the KSA are characterised by salinity, which causes a major problem in different regions of the country. The drainage water is likely to contribute to groundwater recharge. Dincer, ***et al.*** (1974b) suggested that mixing between aquifers and recirculating irrigation water for recharge are the most plausible explanation for the similarities found in chemical composition, salinity, and isotopic content (using ^{18}O) of water sampled from Umm er Radhuma, Neogene, Khobar, and Alat aquifers in the eastern region.

To conclude this section, it has been shown that ground water is an essential water resource for the KSA. It is thus important to protect ground water from depletion or/and quality degradation. Water used in agriculture is the most consumed water. Irrigation water may perhaps contribute to ground water recharge. The drainage water leaches out excess NO_3^--N from root zone, and so possibly to ground water. This suggests that efficient agricultural practices are needed, and perhaps most importantly N fertilisation.

Table 2.6. Water demand and supply (X 10^6 m^3 y^{-1}) in the KSA (AL-Ibrahim, 1991).

Year	1980		1985	
	amount	%	amount	%
Demand:				
Agriculture	1860	79	7430	84
Domestic, industrial, and other	503	21	1400	16
Total	2362	100	8830	100
Supply				
Water surface	485	20	900	10
Groundwater:				
renewable	660	28	950	11
non-renewable	1154	49	6480	73
Desalinated sea water	63	3	400	5
Reclaimed wastewater	-	-	100	1
Total	2362	100	8830	100

7- AGRICULTURAL PROGRESS.

The agricultural sector in the KSA has evolved from local traditional practices in the different oases scattered throughout the country to more planned and organized affairs. Such planning has brought the country eminent achievements in agriculture, which have been studied in detail by several investigators (e.g., EL-Mallakh, 1982; COMET, 1984; Joffe, 1985; Rahman and AL-Shaikh, 1988).

The objective of this section is to discuss the advances of the KSA in agriculture and their relationship with the increase in the use of N fertilisers. The discussion includes:

1- The Saudi achievements in agriculture.

2- The increase in consumption of N fertilisers.

7.1- THE SAUDI ACHIEVEMENTS IN AGRICULTURE:

Agricultural production (i.e., both agronomy and animal sectors) has increased extensively in the KSA since the late seventies. For instance, from 1978/79 to 1983/84 wheat production increased from 17,505 to 865,000 t. These advances in Saudi agriculture have received international acclaim. In November 1984, the MAW was awarded a certificate of merit by the Food and Agriculture Organization (FAO) for the progress that helped the country to become self-sufficient in wheat production (Saudi Arabian Exhibition, 1986).

These achievements have continued in the subsequent years. Increases in the total cultivated area and production of some crops are shown in Table 2.7, and that of the animal production sector in Table 2.8. The data presented in both tables are summarised from different reports published by the Department of Economic Studies and Statistics (DESS) of MAW and the Department of General Statistics (DGS) of the Ministry of Finance and National Economic (MFNE).

Table 2.7 shows that the total cultivated area increased 85% between 1984 and 1991. Most of this increase occurred in the area used for cereal production (i.e., 72% of the total in 1991). Cereal production has always been dominated by wheat production. For example, in 1991 wheat production was 3.934 X 10^6 t (87% of total cereal production) cultivated on an area of 0.864 X10^6 ha (83% of total area for cereal) (DGS, 1992).

The increase in cultivated area has also been accompanied by an improvement in production per unit area (DESS, 1990; Ministery of Planning (MOP), 1990; DESS, 1993). MOP (1990) indicated that for many crops 3% annual increase in production per ha was obtained between 1985 to 1990. DESS (1993) suggested that in some specialized projects (i.e., large scale projects) wheat production reached 7 t ha^{-1}. These improvements were achieved due to the adoption of modern agricultural technology particularly advanced irrigation systems (i.e., centre pivot). In 1990, there were more than 22000 centre pivot units being used in the country (DESS, 1990).

As indicated, the animal sector has also advanced in the KSA. Table 2.8 shows that the total number of animals in the country steadily increased from 1974/75 to 1992. In the same period the number of animals increased 50 times.

This increase in animals has helped the country to be self-sufficient in some related products (e.g., table eggs and fresh milk) and increased the country's self-sufficiency in others (e.g., 72 and 75% of white and red meat, respectively) (MOP, 1990).

Table 2.7. The advances in cultivated area and some agricultural products in the KSA.

Year	Cultivated area (ha)				Production ($X10^6$ t)		Reference.
	cereals ($X10^6$)	fruit	fodder	total ($X10^6$)	cereals	vegetables	
1984	0.450	N.A.	170,543	0.782	1.448	N.A.	DESS, 1988
1985	0.634	N.A.	145,086	0.946	2.191	N.A.	DESS, 1988
1986	0.643	N.A.	139,050	0.947	2.463	0.866	DESS, 1990
1987	0.718	N.A.	163,322	1.062	2.934	0.991	DESS, 1990
1988	0.898	N.A.	167,870	1.245	3.795	0.977	DESS, 1990
1989*	0.968	87,520	166,503	1.326	3.950	1.008b	b DESS, 1990 & DGS, 1990
1990*	0.978	90,943	200,996	1.379	4.138	1.045b	b DESS, 1990 & DGS, 1990
1991E	1.045	92,609	190,843	1.443	4.507	NA	DESS, 1990

N.B. * all data are from DGS (1990), unless as indicated. E refers to estimated data, and NA means no available data.

Table 2.8. Advances in the sector of animal production in the KSA.

Year	Type of animal (X 10^6)						Reference
	poultry	goats	cows	sheep	camels	Total	
	birds	heads					
1974/75	0.826	1.242	0.282	2.148	0.105	4.603	DESS, 1988
1984	147.769	3.099	0.271	6.940	0.391	158.470	DESS, 1988
1986	199.699	3.091	0.303	7.117	0.377	210.587	DESS, 1988
1989	215.834	3.114	0.194	6.173	0.406	225.721	DGS, 1992
1990	218.482	3.406	0.193	6.383	0.406	228.870	DGS, 1992
1992	218.530	3.337	0.200	6.847	0.412	229.326	DGS, 1992

The advances in agriculture could not be possible without the generous aids of the government at all levels. H. E. Minister of Agriculture and Water stated in his speech in the International Conference held in Rome, November 15 1996, that to the year of 1995 the government has paid to the citizens more than SR28 X 10^9 ($7.5 X 10^9) loans with no interest. Also, there was an amount of SR11 X 109 ($2.9 X109) which was paid as non-refunded aids (Riyadh News Paper, 1996). The governmental aids and subsidies for agricultural production are shown in Appendix A-2.4.

This leads to the conclusion that agriculture in the KSA has advanced remarkably. The advances are horizontal (in total area cultivated) and vertical (in yields per a unit area), which demand intensive use of nutrients, in particular N, as will be discussed in the following section. The intensive demands for N are attributed to the poor soil fertility characteristic of soils in the KSA (See Section 5)

7.2- THE INCREASE IN CONSUMPTION OF N FERTILISERS:

Advances in agriculture led to an increase in the consumption of N fertilisers. Figure 2.3 shows the relationship between advances in agriculture and consumption of N fertiliser in the KSA. In Figure 2.3, advances in agricultural production have been estimated as indices calculated on basis of 1978/81 being equal to 100 (FAO, 1993).

Figure 2.3 shows that increases in agriculture and N consumption generally exhibit a similar trend. This indicates the effects of N fertilisers on agricultural production, agreeing with the suggestion by Ismaiel (1989). It is expected because poor soil fertility is one of the dominant properties of soils in the KSA (Section 5).

Also, Figure 2.3 shows that N consumption increased about 11 times from 1981 to 1992 (i.e., from 25 to 284 X 10^3 Mt, respectively). The main type of N fertilisers used in the Kingdom is urea. Figure 2.4 shows the use of urea compared to other N complex fertilisers between 1979/80 and 1989/90. Urea forms almost 60% or more of the N fertilisers consumed in the period.

This leads to the conclusion that N fertilisers were used intensively in the last decade, and suggests the possibility of NO_3^--N loss by leaching. The possibility of NO_3^--N loss by leaching increases when other sources of N are used, as will be discussed in the following section. Besides the economic considerations, losses of

NO_3^--N by leaching cause adverse effects on the environment and natural resources (Already indicated in Chapter One).

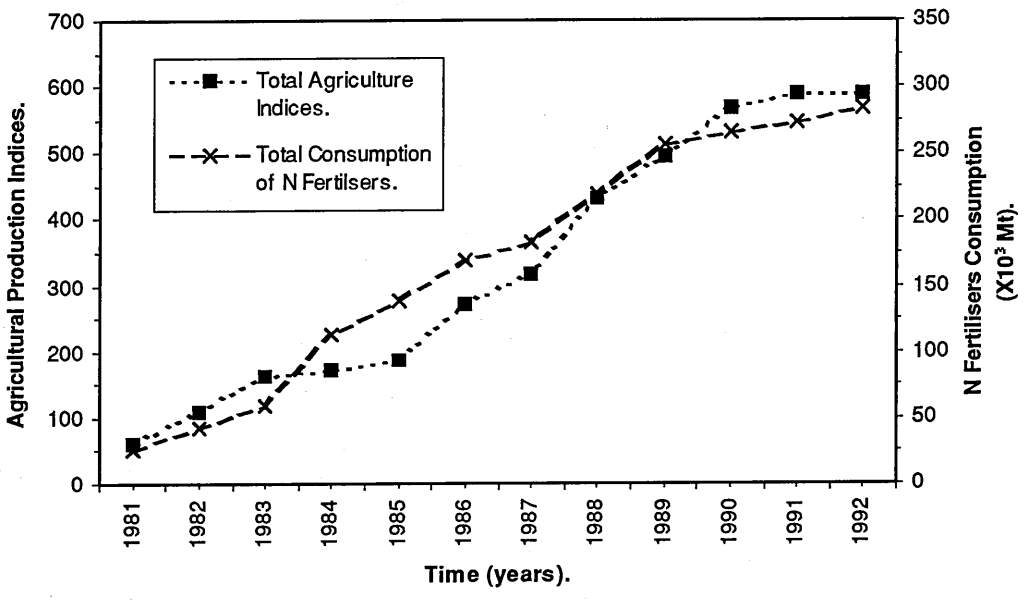


Figure 2.3. The increase in total consumption of N fertilisers as related to the advances in agriculture in the KSA (FAO, 1985; 1990; 1993).

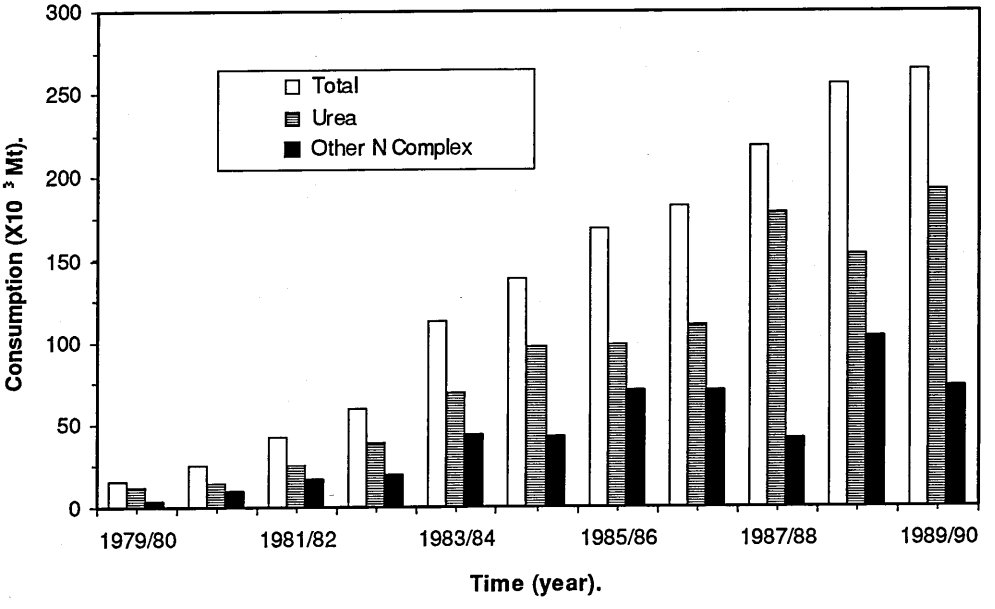


Figure 2.4. The different types of N fertilisers consumed in the KSA (FAO, 1985 & 1990).

8- PRELIMINARY N BUDGET.

Planning a N budget for an area is a beneficial tool for evaluating N fertilisation programmes and to determine the prevailing input and output processes. A preliminary N budget has therefore been estimated for the KSA.

The budget was estimated for the wheat crop grown in Gassim region. This region was chosen because it is one of the major agricultural regions. In 1990, it was the second ranked region in the Kingdom for the cultivated area (i.e., 24% of total cultivated area) and for wheat production (i.e., 32% of total production) (DESS, 1990). Wheat was selected as it is the predominant crop in the KSA as indicated above (Section 7.1).

N quantities (kg N ha^{-1}) of both annual inputs and outputs were calculated independently, and in the manner described by Meisinger & Randall (1991). The data used for the calculations are summarised in Table 2.9.

The application rates of FYM were based on the experience of various experiments undertaken in the country. In these experiments, 30 to 40 t FYM ha^{-1} were used (AL-Noaim & Farnworth, 1972 & 1973; Farnworth, 1973). In an experiment conducted in Hassa region, 150 t ha^{-1} of cattle FYM was used (Farnworth & Ruxton, 1974). As well, Dr. Earl Charle (personal communication) suggested that assuming application rates between 20 and 40 t ha^{-1} of FYM is a reasonable estimate.

The quantity of N loss by leaching was determined assuming 40% leaching losses of the total N applied. This percentage is an approximate average of different investigations in which N leaching losses ranging between 26 and 62% of applied N were observed (Bingham, ***et al.***, 1984; Pratt, 1984; Roberts, 1987; Burt & Haycock, 1993; Jones & Schwab, 1993).

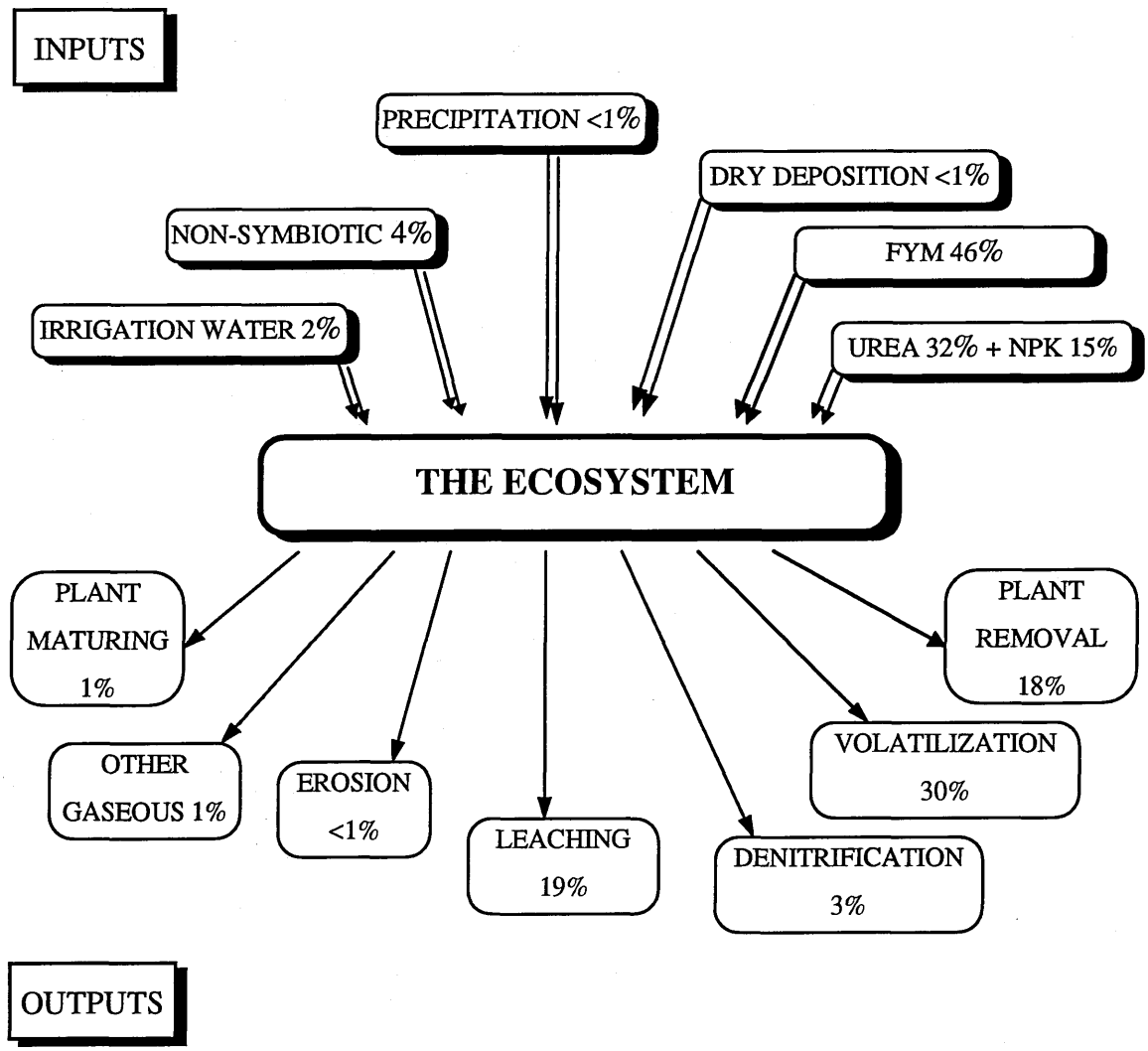
Figure 2.5 illustrates the preliminary N budget estimated for Gassim region in the KSA. The Figure shows that the prevailing sources of N to the ecosystem are N fertilisation (i.e., 47% from urea + NPK) and application of FYM (i.e., 47%). This suggests that application of FYM in rates of 30 t ha^{-1} or more is a major source of N.

The N from the applied FYM however has to be mineralised before it becomes available to plants. This mineralisation process is affected by various factors as already indicated (Section 3.1, Chapter One).

Table 2.9. Data used for estimating N budget of Gassim region in the KSA.

Item	Quantity and Unit	Source
Average of application rates of farm-yard manure	3 X 10^4 kg N_{or} ha^{-1}	AL-Noaim & Farnworth (1972 & 1973); Farnworth (1973); Dr. Earl Charle (Pers. Comm.)
% of N in organic materials	5%N	Bear (1964); Franco & Munns (1982)
% of soil organic matter	0.76%	Shadfan & Hussen (1987)
N fertilizers application rates:		GAC (1987)
Urea (46 %N)	454.4 kg-Urea ha^{-1}	
NPK (23%N)	435 kg-NPK ha^{-1}	
Average rainfall	150 mm y^{-1}	Shadfan & Hussen (1987)
N concentrations in rainfall:		Ahmed, ***et al.*** (1990)
NH_4^+-N	0.003 mg NH_4 ℓ^{-1}	
NO_3^--N	0.003 mg NO_3 ℓ^{-1}	
NO_2^--N	0.002 mg NO_2 ℓ^{-1}	
Amount of irrigation applied	5340.4 m^3 ha^{-1}	GAC (1987)
Average of wheat yield	5060 kg ha^{-1}	GAC (1987)
Seeding rates	186.6 kg ha^{-1}	GAC (1987)
N in the system:		Skujinš (1981)
Exchangeable (soluble) NH_4^+- N	0-5 µg-NH_4-N ℓ^{-1}	
NO_3^--N	1-2 µg-NO_3-N ℓ^{-1}	

N.B.: GAC is Gassim Agricultural Company. N_{or} refers to Organic nitrogen.



Total N inputs were equal to 651 kg-N ha^{-1} y^{-1}.
Total N outputs were equal to 467 kg-N ha^{-1} y^{-1}.
N not accounted for was equal to 184 kg-N ha^{-1} y^{-1}.

Figure 2.5. The preliminary N budget for Gassim area in the KSA.

Figure 2.5 shows that N loss through leaching (i.e., 19%) is a major output process that needs considerable attention. Assuming 70% irrigation efficiency, this amount of N in leachate will result in a concentration of 77 mg l^{-1}, exceeding by far the acceptable limits of N in drinking water (Table 1.5).

A preliminary N budget also demonstrates that there will be a quantity of 184 kg ha^{-1} y^{-1} not accounted for, which is residual N in the ecosystem. This quantity may remain in the soil profile to be utilised by the following crop, or may be leached out from the root zone before the following season. It therefore suggests that further N leaching losses are likely.

In conclusion, the estimated N budget has illustrated the plausible contamination process that may deteriorate the quality of ground water in the KSA. Agricultural practices undertaken in the country determine the magnitude of this process. The process is presumably long term. FYM application of 30 t ha^{-1} or more is a major source of N. The release of N from FYM applied is a function of various factors, which are also affected by the agricultural activity. The budget also shows the needs for further investigations to understand N fertilisation practices in the country, so N best management can be achieved.

CHAPTER THREE

EXPERIMENT ONE

EFFECTS OF INTERMITTENT WETTING-DRYING CONDITIONS ON N TRANSFORMATION FROM DIFFERENT APPLICATION RATES OF FARM-YARD MANURE

1- INTRODUCTION:

Nitrogen (N) is the nutrient most frequently limiting crop growth and production. In most soils more than 90% of the total N is contributed by microbial decomposition of organic N-containing compounds derived from plant and animal remains (Stevenson, 1982; Haynes 1986b).

The application of organic material, e.g. farm-yard manure (FYM), was found to amend the poor properties of the soils. It has been suggested that the applications of FYM improve the soil physical properties (Azevedo & Stout, 1974; Tiarks, ***et al.***, 1974; Unger & Stewart, 1974; Hamblin & Davis, 1977; Al-Mukhtar & Zien, 1984; Castellanos & Muñoz, 1985; Sweeten & Mathers, 1985; Hudson, 1994; Herric & Lal, 1995; Schjønning, ***et al.***, 1995), soil chemical properties (Azevedo & Stout, 1974; Tiarks, ***et al.***, 1974; Heggi & Abou-El-Ezz, 1984; Castellanos & Muñoz, 1985; Sahs & Lesoing, 1985; Sommerfeldt, ***et al.***, 1988; Ndayegamiye & Cõté, 1989; Manley, ***et al.***, 1995; Schjønning, ***et al.***, 1995), and soil biological properties (Azevedo & Stout, 1974; Ndayegamiye & Cõté, 1989).

FYM may also be applied to the soil to make up the soil organic matter (SOM) and N depleted by cultivation. Schmidt & Schmidt (1963) found that soils of cultivated lands showed lower values of SOM and N content than adjacent soils of veld lands.

As indicated in Chapter One, continuous application of animal manure is one of the main sources which increases soil N in cultivated lands. However, this organically bound N is unavailable to plant until it is mineralised into NH_4^+-N and NO_3^--N.

The process of decomposition is however affected by the moisture conditions (Reichman, ***et al.***, 1966; Stanford & Smith, 1972). In irrigated lands, the moisture conditions vary in between irrigation, which is a common practice in areas under warm and dry weather.

As observed by the author, the application of FYM to irrigated fields to improve soil properties is a widespread practice in the Kingdom of Saudi Arabia (KSA).

1.1- HYPOTHESIS:

Thus, it is hypothesized that that different wetting-drying conditions resulting from intermittent water application by irrigation affect the microbial release of N from the applied FYM.

1.2- AIM

This study aims to investigate the effects of intermittent wetting-drying conditions on N release from different application rates of FYM.

1.3- OBJECTIVES:

This study involved a pot experiment conducted under a controlled temperature environment (20°C). The objectives of this experiment are:

1- To study the effects of different wetting-drying conditions on N release from the applied FYM.

2- To investigate the amount of N mineralised from different application rates of FYM.

3- To examine the N forms transformed from the applied FYM.

2- EXPERIMENTAL DESIGN:

The pot experiment conducted in this study comprised four FYM application rates and three wetting-drying cycles. The FYM application rates were 0, 20, 30, and 40 t ha^{-1} (Y0, Y1, Y2, and Y3 treatments, respectively).

The FYM was obtained from A. G. Burton's Dairy Cattle Farm, Silsoe Village, UK. It was collected from the cattle feedlot, air dried, ground, sieved, and mixed. The drying was done in a glasshouse at the Agricultural Water Management Department, Silsoe College, Cranfield University. The sieving was done using a 1 mm sieve (mesh No. 16).

5 samples from the FYM used were analyzed for the total nitrogen (TN) using a Buchi equipment (Digestion Unit 435, Distillation Unit B316, and Scrubber Unit 412),

and for organic carbon (OC) by the Loss on Ignition (LOI) method (BSI, 1990a). The values of TN and OC of the FYM used are summarised in Table 3.1.

Table 3.1. The summary of total nitrogen (TN) and organic carbon (OC) values for the FYM used.

Item	Total analysis	Range (%)	Average (%)	S.D. (%)	C.V. (%)
TN	5	2.60-2.66	2.63	0.03	1.20
OC	5	48.04-50.25	49.80	0.47	0.95

N.B.: S.D. and C.V. refer to standard deviation and coefficient of variations, respectively.

Water was applied every 2, 4, or 6 days (M1, M2, and M3 treatments, respectively). The treatments included in the experiment are summarised in Table 3.2. Each treatment was replicated three times.

Table 3.2. The combination of the FYM-wetting treatments used in the study.

Wetting		FYM Treatments			
Treatment	Interval (days)	Y0	Y1	Y2	Y3
		0 t ha^{-1}	20 t ha^{-1}	30 t ha^{-1}	40 t ha^{-1}
M1	2	Y0M1	Y1M1	Y2M1	Y3M1
M2	4	Y0M2	Y1M2	Y2M2	Y3M2
M3	6	Y0M3	Y1M3	Y2M3	Y3M3

The wetting cycles were chosen to simulate irrigation practices. They were designed based on results of a drying trial. The trial was conducted prior to the experiment to observe the temporal change in moisture contents for the sample pots under the same temperature.

The trial was done using a FYM application rate equivalent to 40 t ha^{-1} with three replicates, which were prepared in a manner similar to sample preparation as will be discussed later. The results of the trial are summarised in Figure 3.1.

The Figure demonstrates the change in water content (ml) in the samples as the free drainage stopped. Water content was then calculated on a basis of weight differences.

Figure 3.1 also shows that the water contents were approximately 50%, 20%, and 10% of the starting value after 2, 4, and 6 days, respectively. After 6 days, the change in water content was small.

This suggests that applying water every 2, 4, or 6 days results in different moisture conditions to which the samples are exposed, as designed. These conditions are within the range of moisture status anticipated under irrigation.

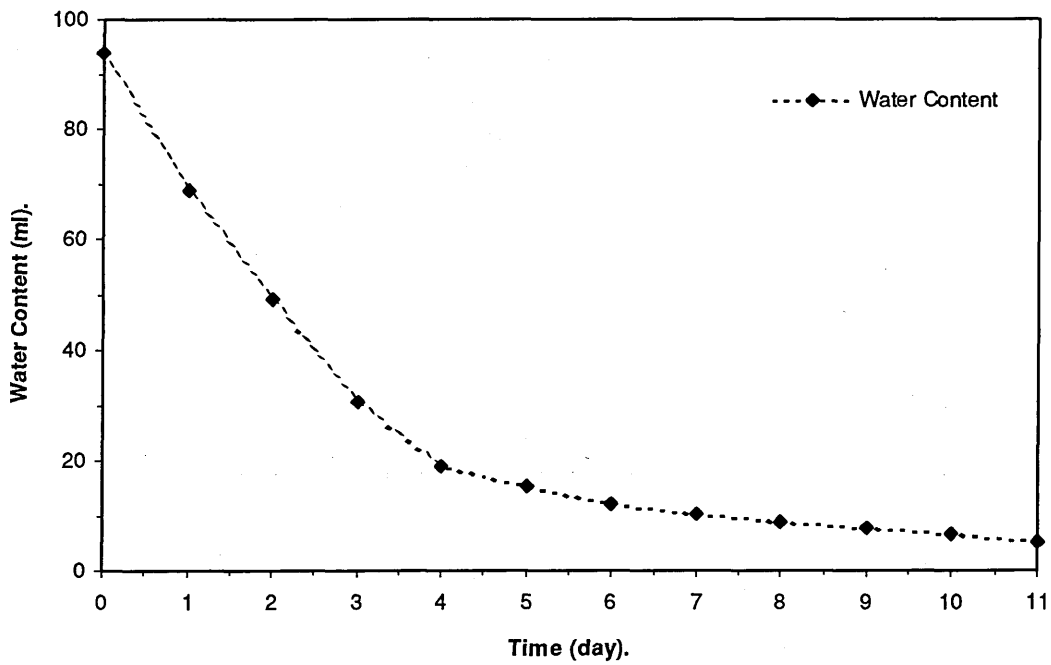


Figure 3.1. The temporal changes in moisture contents for the pots under 20°C.

3- MATERIALS AND EXPERIMENTAL PROCEDURE:

3.1- MATERIALS:

The materials used in this experiments were plastic pots (0.5 *l* capacity), FYM ground and sieved through 1 mm (16 mesh), un-modified sand, woven steel mesh, scotch brite, balance (Sartorius 1507, capacity 5500 gm ± 10mg), and distilled water.

3.2- EXPERIMENTAL PROCEDURE:

This experiment was started on August 29 1994 and ceased on October 29 1994, with an incubation period of 62 days. 36 pots were used in the experiment. Each pot was prepared as follows:

The weight of the FYM corresponding to the equivalent application rate was mixed individually with 500 gm of sand (Table 3.3). This mixing technique was found to be the most appropriate. It ensures that an equal amount of FYM present in every pot of every FYM treatment.

The mixture was then placed in a pot, which contained a woven steel mesh and scotch brite on the bottom. The mesh and the brite were used to prevent the mixture loss and to allow free drainage from the bottom of the pot.

Table 3.3. The weight of FYM applied to every FYM treatment.

Treatment	Applied FYM		Applied N
	t ha^{-1}	gm pot^{-1}	mg pot^{-1}
Y0	0	0	0
Y1	20	3.85	101.26
Y2	30	5.77	151.75
Y3	40	7.70	202.51

All pots were randomly distributed on a table placed in a temperature controlled room at 20°C in the Crendon building, Silsoe College, Cranfield University.

Water was applied every 2, 4, or 6 days. The applied volume was equal to two volumes of water. The first was the water retained in the sample prior to water application, and the second was the volume of water needed to bring each sample to field capacity (FC).

The water retained was calculated on a basis of weight differences between the wet and dry weights of the sample. The wet weight was the weight of the sample after water application as the free drainage stopped, whilst the dry weight was the weight of

the sample prior to water application. The volume of water needed to bring the sample to FC was determined from the first water event.

Effluent samples (the time series) were collected from the pots as they were watered. They were then stored at 4°C. A bulked sample was made for every replicate by accumulating 5 ml from the collected time series effluent samples. The bulked samples were preserved with mercuric chloride (40 mg Hg Cl_2 l^{-1}) with a final concentration of 1 ml of Hg Cl_2 per 100 ml of effluent sample. The bulked samples were also stored at 4°C (Allen, 1989).

Both the time series and bulked samples were analyzed for nitrate (NO_3^--N) and ammonium (NH_4^+-N) using a Technicon Auto-Analyzer II. Total soluble nitrogen (TSN) was determined in both samples by the autoclave method (Williams, ***et al.***, 1995).

Throughout the study, all results of N are expressed in mg unless otherwise stated. This is done for two reasons. The first is to minimise variations in N concentrations between replicates, which are possibly caused by differences in leachate volume. The second is to calculate N budget using the N mass unit (mg).

Total soluble salts (EC) and acidity were determined in the time series samples using Jenway 4070 and Camlab CG837 probes, respectively. The EC values are expressed in dS m^{-1}.

After the experiment ceased soil samples were analyzed for total nitrogen (TN) using a Buchi equipment (Digestion Unit 435, Distillation Unit B316, and Scrubber Unit 412).

All the details of the analytical methods used in this experiment are outlined in Appendix A-1.

4- RESULTS AND DISCUSSION:

As already indicated (Sections 1.2 and 1.3), this pot experiment aims to examine the N released from the FYM applied at different rates under intermittent wetting drying conditions. Four FYM application rates and three wetting drying cycles were used in this experiment (Table 3.2, Section 2).

This section aims to discuss the results of this experiment. The discussion includes:

1- Results of soil moisture.

2- Results of (N) recovered in effluent.

3- Results of total soluble salts (EC) and acidity (pH).

4.1- RESULTS OF SOIL MOISTURE:

It was indicated earlier (Section 2), this experiment was designed to subject the FYM applied at different rates to different moisture regimes. These regimes were obtained by intermittent water application.

The objective of this section is to examine the differences in moisture conditions provided by the planned wetting treatments.

Water contents were calculated for every FYM treatment prior to and after water application as the drainage stopped. The calculations were based on dry weight of the pots.

Moisture variations for the FYM treatments studied are shown in Figures A-3.1 to A-3.6 included in Appendix A-3. The range and average of moisture values found in these Figures are summarised in Table 3.4.

Table 3.4 shows that the wetting treatments had an approximately equal range and average moisture values after water application. This indicates that the starting moisture conditions of incubating intervals were similar at every wetting event for all the treatments.

Prior to water application however moisture values decreased as the wetting intervals increased, following an order of M1 > M2 > M3 (Table 3.4).

This suggests that the purpose of this pot experiment to subject micro-organisms responsible for N mineralisation to different moisture conditions was achieved. Thus the amount of N mineralised from the applied FYM was expected to differ as a result of differences in moisture conditions.

Table 3.4. Summary of moisture variations for the FYM treatments.

Treatments		Moisture values (%)			
Wetting	FYM	Prior to water application		After water application	
		range	average	range	average
M1	Y0	6.27-15.25	12.22	19.27-22.47	20.03
	Y1	8.62-18.44	16.16	21.58-23.56	22.54
	Y2	8.33-18.40	16.39	21.64-23.76	22.87
	Y3	7.79-17.23	14.59	21.56-23.60	22.41
M2	Y0	4.20-10.12	6.43	19.14-22.86	19.71
	Y1	5.96-10.86	8.11	20.51-22.36	21.13
	Y2	5.21-10.18	7.65	21.13-22.17	21.46
	Y3	5.65-10.14	7.91	21.34-23.26	21.59
M3	Y0	1.57-4.32	2.65	19.45-22.66	20.01
	Y1	3.90-8.09	5.15	20.79-22.53	21.34
	Y2	3.91-8.81	5.86	21.20-22.60	21.67
	Y3	4.44-8.94	6.04	20.48-23.33	21.92

4.2- RESULTS OF N RECOVERED IN EFFLUENT:

As indicated earlier (Section 3.2), effluent samples collected from the pots were analyzed for NO_3^--N, NH_4^+-N, and TSN. The analysis was done for both the time series and the bulked samples.

This section aims to discuss the results of these analyses. The discussion includes:

1- Leached NH_4^+-N.

2- Leached NO_3^--N.

3- N in effluent samples.

4- N budgets.

4.2.1- NH_4^+-N leached:

The results of NH_4^+-N (mg) recovered in the effluent collected from the different FYM application rates under the M1, M2, and M3 treatments are shown in Figures 3.2.a, 3.2.b, and 3.2.c, respectively.

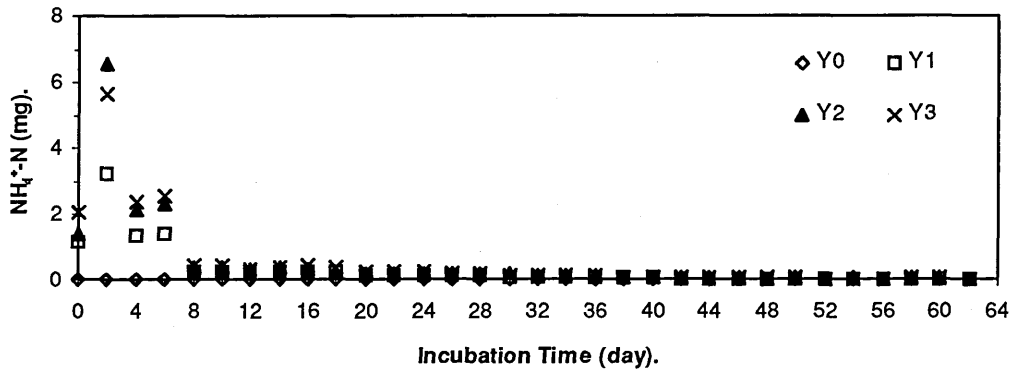


Figure 3.2.a. NH_4^+-N recovered from the different FYM rates under the M1 treatment.

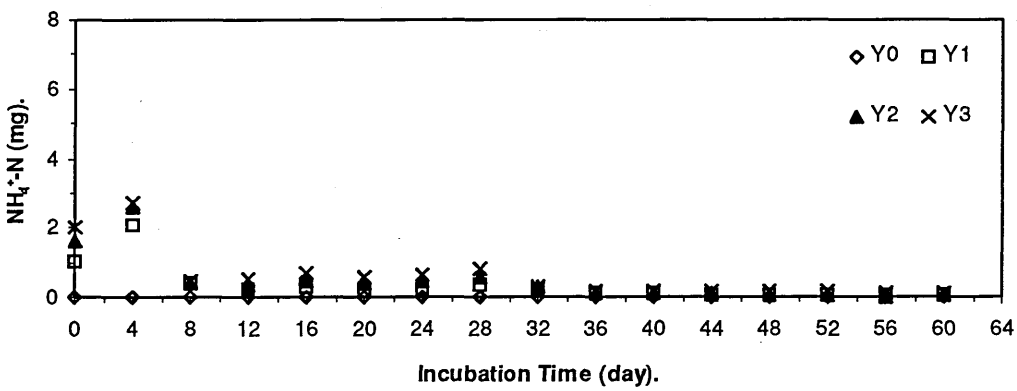


Figure 3.2.b. NH_4^+-N recovered from the different FYM rates under the M2 treatment.

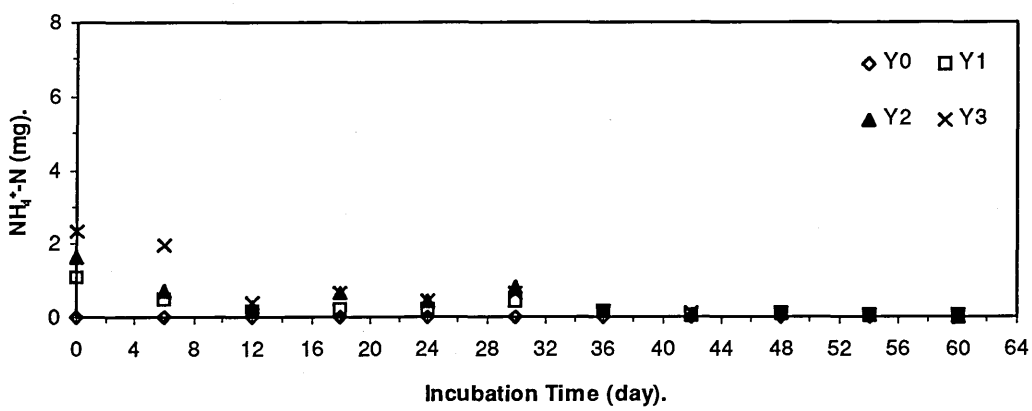


Figure 3.2.c. NH_4^+-N recovered from the different FYM rates under the M3 treatment.

Figures 3.2.a, 3.2.b, and 3.2.c show that the maximum NH_4^+-N values occurred in the first four wetting events, after which the amount of N mineralised decreased to values less than 1 mg for all the FYM-wetting treatments.

Figures 3.2a, 3.2b, and 3.2c also show that the NH_4^+-N peak values increased as the moisture conditions increased. The values of NH_4^+-N peaks for the FYM application rates under the different moisture conditions are summarised in Table 3.5. Table 3.5 also includes the $LSD_{0.05}$ values for all the FYM and wetting treatments.

Table 3.5. Summary of the values of NH_4^+-N peaks (mg) observed for the FYM treatments under different moisture conditions.

Treatments	Y0	Y1	Y2	Y3	$LSD_{0.05}$
M1	0.02	3.19	6.57	5.64	1.12
M2	0.02	2.08	2.62	2.71	1.36
M3	0.01	1.10	1.63	2.35	0.59
$LSD_{0.05}$	NS	0.64	1.94	0.94	

N.B.: NS means not significant.

For each FYM application rate, Table 3.5 shows that the values of NH_4^+-N peaks were significantly different (P = 0.05) between the wetting treatments, with the exception for the Y0 treatment. This indicates that N mineralised from the applied FYM is affected by moisture conditions, agreeing with the findings of other investigators (Birch, 1964; Reichman, ***et al.***, 1966; Stanford & Smith, 1972).

Under every wetting treatment, different FYM application rates also showed significant differences (P = 0.05) in the NH_4^+-N peak values (Table 3.5). These differences, however, were markedly less than differences caused by the moisture conditions.

This leads us to conclude that the moisture conditions had a greater effect on the amount of N mineralised from the applied FYM than the application rates, suggesting a need for further investigation on higher FYM application rates than those used to

verify such observations. The rates should be examined under the same wetting strategy.

4.2.2- NO_3^--N leached:

The results of NO_3^--N (mg) recovered in the effluent collected from the FYM treatments under the M1, M2, and M3 treatments are shown in Figures 3.3.a, 3.3.b, and 3.3.c, respectively.

Figures 3.1.a, 1.b, and 3.1.c show that NO_3^--N values were generally small, being less than 0.20 mg for all the FYM treatments under the different wetting conditions. There was no consistent pattern observed for the FYM or wetting treatments. This indicates that nitrification did not occur during this experiment, as expected.

The absence of nitrification is likely to be because of a lack of nitrifying bacteria in the FYM-sand mixture. Witzel, ***et al.*** (1966) observed that bovine manure contains different types of micro-organisms capable of decomposing the manure. These micro-organisms however were not expected to carry out nitrification, which is performed by specific bacteria, *Nitrosomonas* and *Nitrobacter* (Focht, & Verstraete, 1977; Schmidt, 1982; Haynes, 1986b; Kuenen & Robertson, 1988).

In cultivated fields, however, nitrification is anticipated to take place due to the presence of nitrifying bacteria. This suggests that introducing a field soil into the FYM-sand mixture would provide the nitrifying bacteria, which convert the NH_4^+-N mineralised from the applied FYM to NO_3^--N, as will be proven later in the study.

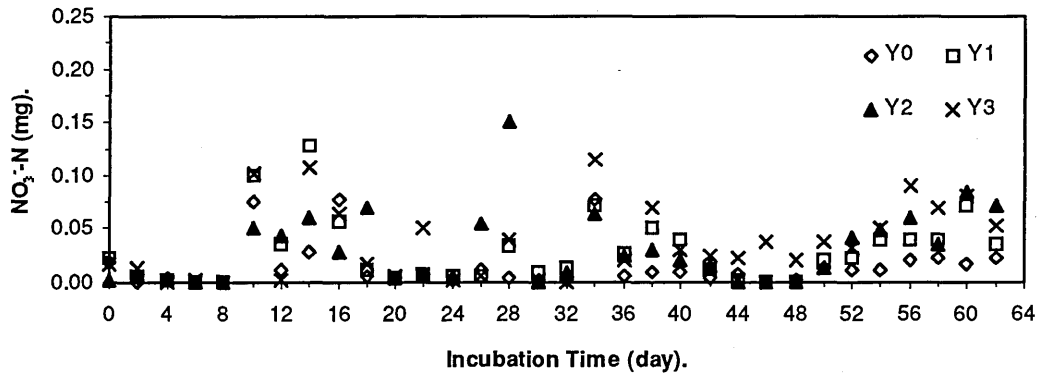


Figure 3.3.a. NO_3^--N values from the FYM treatments under the M1 treatment.

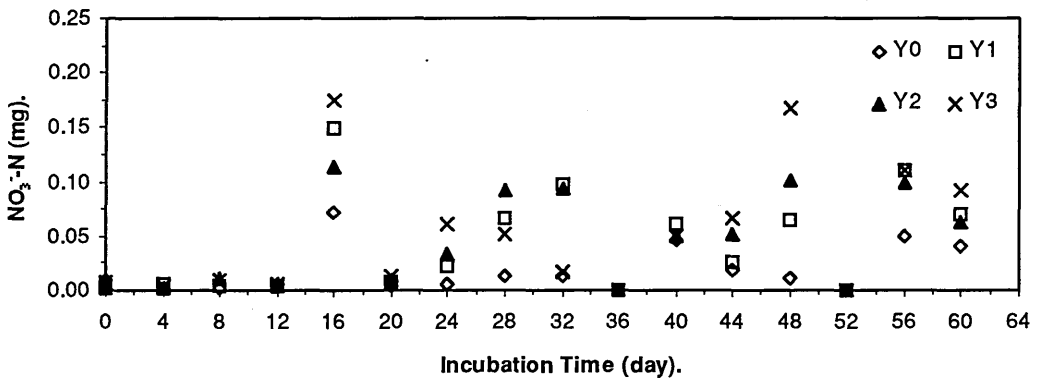


Figure 3.3.b. NO_3^--N values from the FYM treatments under the M2 treatment.

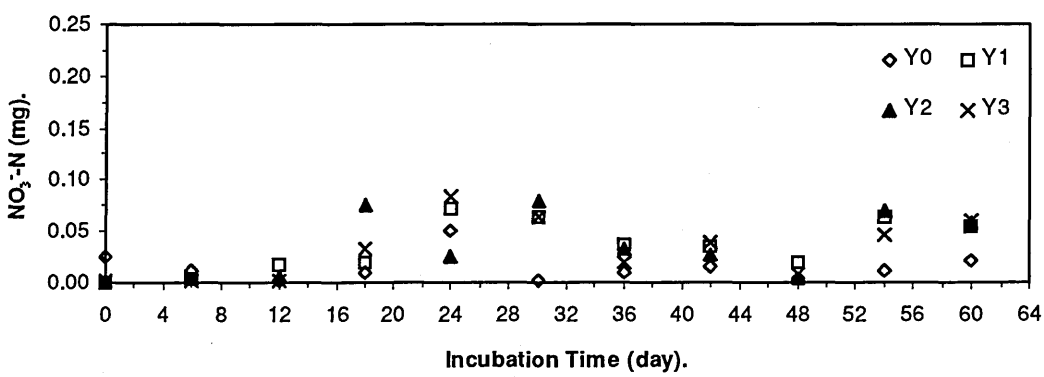


Figure 3.3.c. NO_3^--N values from the FYM treatments under the M3 treatment.

4.2.3- N in effluent-summary:

N recovered (mg) in the effluent samples collected from the pots is summarised in Table 3.6. The table includes the mass values of NH_4^+-N, NO_3^--N, and TSN for both the time series and the bulked samples (Section 3.2).

Table 3.6 shows that the NH_4^+-N values for both the time series and the bulked samples increased as the moisture conditions increased. The TSN values also showed a similar trend. This agrees with the trend seen for the values of NH_4^+-N peaks (Section 4.2.1), which ascertains the observed effects of moisture conditions on the amount of N mineralised from the applied FYM.

Table 3.6. Summary of N recovered in the effluent samples collected.

Treatments		NH_4^+-N		NO_3^--N		TSN	
		time series	bulked	time series	bulked	time series	bulked
wetting	FYM	(mg)					
M1	Y0	0.41	ND	0.49	ND	2.50	ND
	Y1	9.59	12.15	0.91	0.83	31.82	33.51
	Y2	16.25	18.53	1.01	1.82	45.16	47.33
	Y3	16.99	23.69	1.18	1.17	57.60	60.44
M2	Y0	0.16	ND	0.29	ND	1.391	ND
	Y1	5.53	6.40	0.69	0.66	19.46	18.53
	Y2	7.61	8.86	0.73	0.81	25.78	24.64
	Y3	9.69	10.85	0.83	1.04	37.11	38.17
M3	Y0	0.05	ND	0.16	ND	0.78	ND
	Y1	3.01	3.21	0.39	0.40	12.99	11.59
	Y2	4.88	5.30	0.38	0.50	19.93	18.02
	Y3	6.96	5.92	0.36	0.45	25.73	24.04

N.B.: ND means not determined.

The NH_4^+-N values for the time series samples were generally smaller than the values for the bulked samples (Table 3.6). This suggests that some NH_4^+-N was possibly lost from the time series samples before analysis, indicating a need for a chemical preservation for all the samples in the following experiments of this study.

For the bulked samples however the TSN values were greater than the NH_4^+-N values (Table 3.6). TSN comprises all the N forms soluble in water including for instance NH_4^+-N, NO_2^--N, NO_3^--N, amino acids, amides, nitriles, di- and poly-amino compounds, and amino alcohols (Vogel, 1970). Thus, the TSN values are the appropriate values to use for calculating N budget in the coming section.

Table 3.6 also shows that the NO_3^--N values for both the time series and the bulked samples were small being generally less than 1% of the applied N (Table 3.3). This confirms the absence of nitrification during the experiment, as already suggested (Section 4.2.2).

4.2.4- N budgets:

As already indicated (Section 3.2), soil samples were analyzed for TN after the experiment ceased. The analysis was done to calculate the N budget.

Table 3.7. N budgets for the FYM-wetting treatments.

Treatments		TN (mg)		N recovered	N not-accounted for	
Wetting	FYM	at the start	at the end	(mg)	(mg)	(%)
M1	Y1	101.26	64.13	33.51	3.62	3.57
	Y2	151.75	96.82	47.33	7.60	5.01
	Y3	202.51	134.61	60.44	7.46	3.68
M2	Y1	101.26	78.72	18.53	4.01	3.96
	Y2	151.75	120.05	24.64	7.06	4.65
	Y3	202.51	152.70	38.17	11.64	5.75
M3	Y1	101.26	82.64	11.59	7.03	6.94
	Y2	151.75	124.36	18.02	9.37	6.17
	Y3	202.51	162.38	24.04	16.09	7.95

N budgets for the applied FYM under the different wetting treatments are summarized in Table 3.7. The table contains the values of TN applied at the start, TN at the end, N recovered in effluent, and differences between them representing the N not-accounted for, which was assumed to be losses in the form of gaseous N

compounds. N recovered in effluent was the TSN values for the bulked samples (Table 3.6), as already discussed (Section 4.2.3).

Table 3.7 shows that for every FYM application rate the TN values at the end increased as the dry conditions increased. This agrees with the observation made in Section 4.2.1, which indicated that the moisture condition had greater effects on N mineralisation than the application rates, confirming the need for further investigation on higher FYM application rates than those used.

Table 3.7 also shows that the percentages of N not-accounted for were small, a possible situation as confirmed by the pH values. This is due to the effects of mixing the FYM with sand on N gaseous loss. Nelson (1982) indicated that the amount of N gaseous losses in the forms of ammonia (NH_3) are small when N fertilizers are incorporated into the soil, and NH_3 losses are normally $\leq$ 15% of the applied N when ammonical fertilizers are surface applied to acidic or neutral soils.

4.3- TOTAL SOLUBLE SALTS AND ACIDITY:

As already indicated (Section 3.2), both total soluble salts (EC) and acidity (pH) were determined in the effluent samples as time series.

The objective of this section is to discuss the results of these determinations as follows:

1- The EC Results.

2- The pH Results.

4.3.1- The EC Results of:

The EC values (dS m^{-1}) in the effluent samples collected from the different FYM application rates under the M1, M2, and M3 treatments are shown in Figures 3.4.a, 3.4.b, and 3.4.c, respectively.

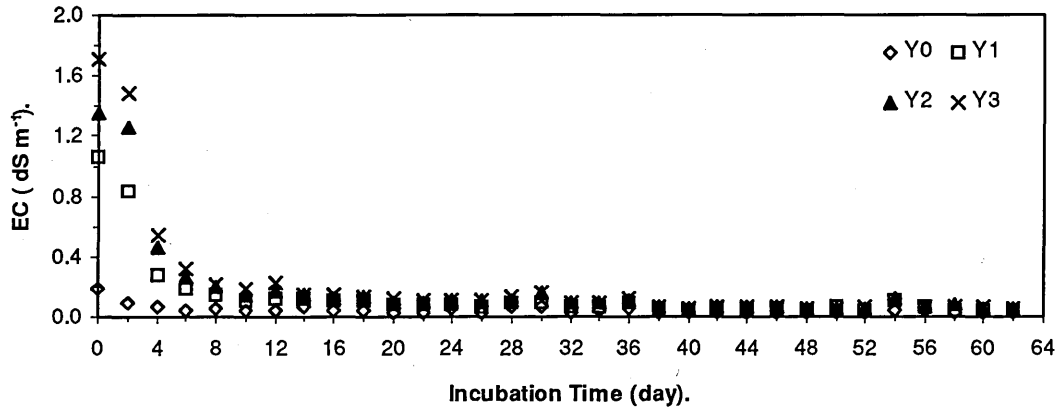


Figure 3.4.a. The EC values for the FYM application rates under the M1 treatment.

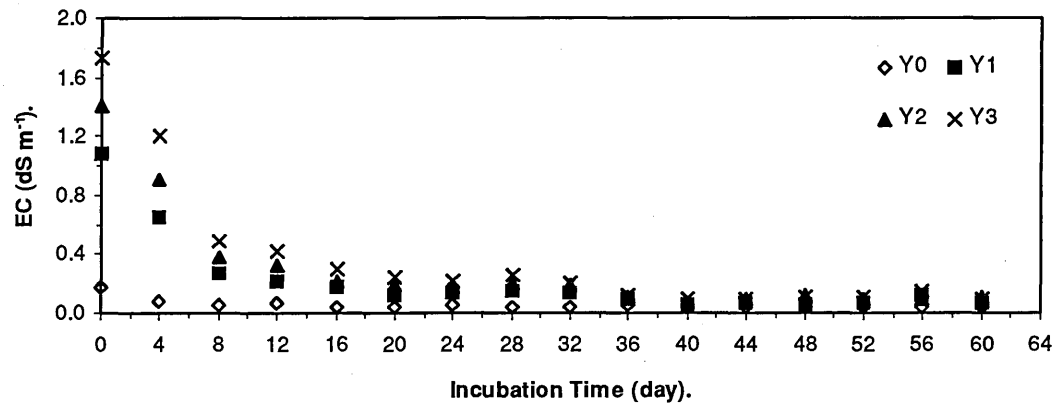


Figure 3.4.b. The EC values for the FYM application rates under the M2 treatment.

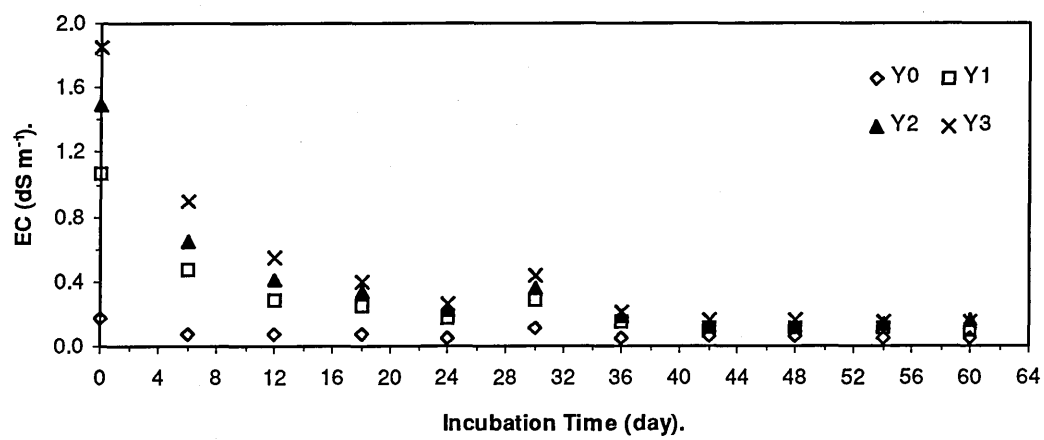


Figure 3.4.c. The EC values for the FYM application rates under the M3 treatment.

Figures 3.4.a, 3.4.b, and 3.4.c show that for all the FYM wetting treatments the highest EC values (generally less than 2 dS m^{-1}) occurred in the first wetting event. These values are expected not to cause any inhibitory effects on micro-organisms responsible for N mineralisation (Singh, ***et al.,*** 1969; McCormic & Wolf, 1980; Groffman, ***et al.***, 1995).

The figures also show that EC values increased as the FYM application rates increased, as expected. Application of FYM was observed to induce salinity and associated problems. McCalla (1974) suggested that excessive applications of solid or liquid wastes produce salt accumulation in soils, which damage crop and soil structure. This implies that using the FYM requires good FYM management that produces the least adverse effects on crop and soil properties.

4.3.2- Results of pH:

The pH values in the effluent samples collected from the different application rates of FYM under the M1, M2, and M3 treatments are shown in Figures 3.5.a, 3.5.b, and 3.5.c, respectively.

The figures show that the pH results for all the FYM wetting treatments were generally in a pH range ($6.5 < pH < 8$), where mineralisation is likely to occur (Adams & Martin, 1984, Keeney, 1980, Killham, 1994).

Also, the pH range observed suggests that excessive NH_3 volatilization is unlikely (Terman, 1977; Schmidt, 1982; Nelson, 1982; Miller & Donahue, 1995), which is another explanation of the small percentages of N not-accounted for (Section 4.2.4, Table 3.7).

In conclusion, both the EC and pH values indicate that N release from the applied FYM has occurred.

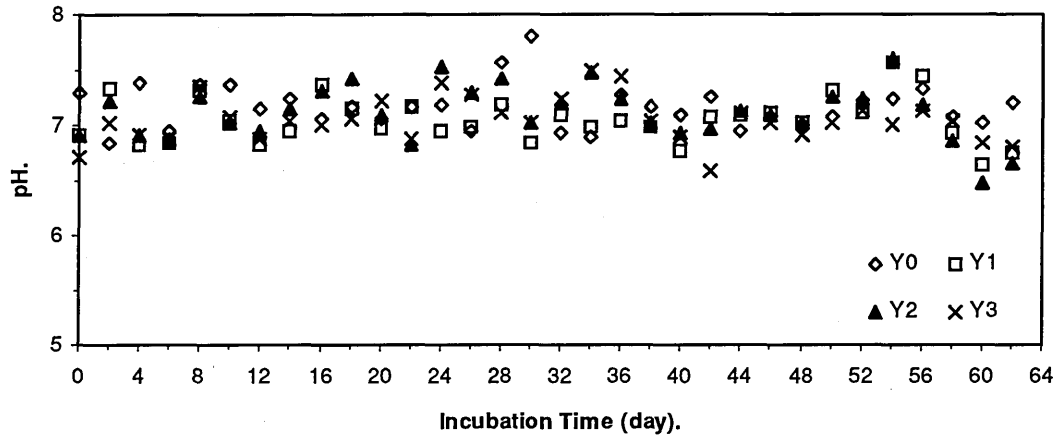


Figure 3.5.a. The pH values for the FYM application rates under the M1 treatment.

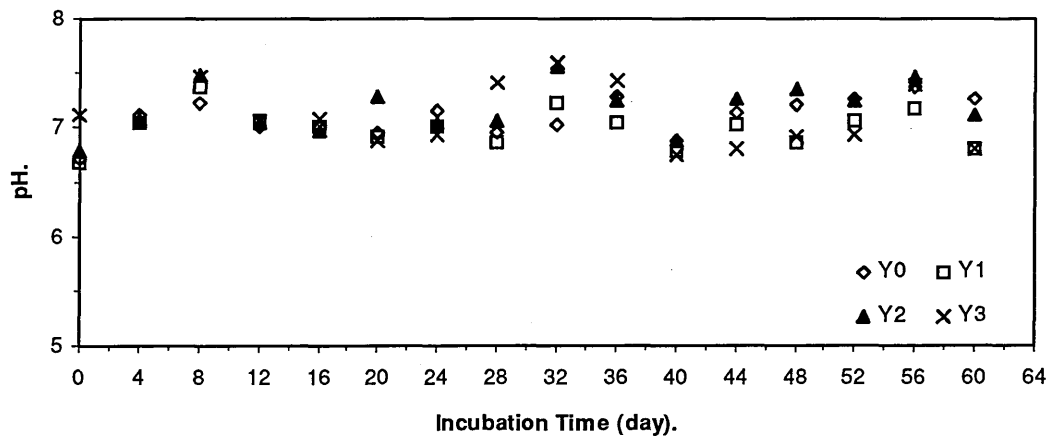


Figure 3.5.b. The pH values for the FYM application rates under the M2 treatment.

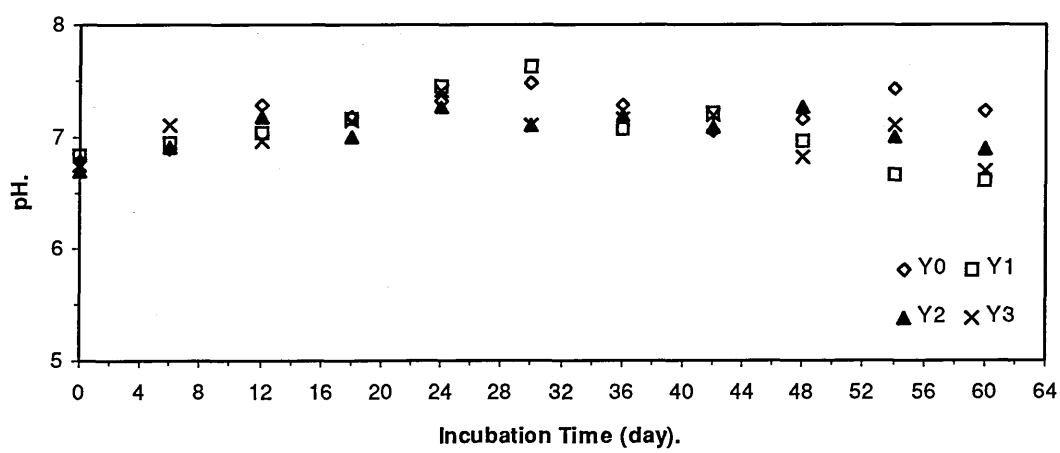


Figure 3.5.c. The pH values for the FYM application rates under the M3 treatment.

5- CONCLUSIONS:

It is concluded from this pot experiment that:

1- The wetting plan adopted had successfully subjected the applied FYM to different intermittent wet-dry conditions simulating conditions under the irrigation practice.

2- These wetting drying conditions resulted in significant differences ($P = 0.05$) between the amount of N mineralised from the applied FYM.

3- The data obtained from this pot experiment showed that the moisture conditions had greater effects on N mineralisation than the FYM application rates. Further investigations involving higher FYM application rates than those used are needed to support such an observation.

4- The NH_4^+-N values for the time series, not chemically preserved, differed from the values of the bulked samples that had been chemically preserved. This emphasizes that all the samples for the forthcoming experiments need to be chemically preserved in addition to the cold storage.

5- NO_3^--N results indicated that nitrification did not occur in the FYM-sand mixture due to the lack of nitrifying bacteria. Thus, introducing a field soil as a source of nitrifying bacteria should be used to enhance nitrification in the mixture, and this finding can be proven.

CHAPTER FOUR

EXPERIMENT TWO

EFFECTS OF DIFFERENT C:N RATIO AND INTERMITTENT WETTING-DRYING CYCLES ON N TRANSFORMATION.

1- INTRODUCTION:

Nitrogen (N) mineralisation from organic materials is a process carried out by different types of micro-organisms. These micro-organisms require mineral N for their cell synthesis in addition to their requirements for carbon (C), which they obtain from the organic material. Energy for their synthesis is obtained from the respiration and the oxidation of these organic materials (Schmidt & Belser, 1982; Wild, 1988).

As discussed earlier (Section 3.2.1, Chapter One), the C:N ratio in soil dictates the direction of the N processes of mineralisation and immobilisation. In cultivated lands, a wide range of C:N ratios is commonly observed world-wide. These result from the agricultural activities involving the use of organic materials, e.g. farm-yard manure (FYM), and inorganic N fertilisers, e.g. ammonium nitrate and urea.

In some of these areas, agricultural activities also demand irrigation practices, which induce varying soil moisture conditions. The moisture condition is another factor that plays a major role in N transformation, as discussed in Section 3.2.2, Chapter One.

1.1- HYPOTHESIS:

It is hypothesized that in irrigated fields containing the FYM applied with urea, both the C:N ratio and the moisture condition influence the activity of micro-organisms performing the processes of N mineralisation-immobilization.

1.2- AIM:

The aim of this study was to examine the effects of intermittent wetting-drying conditions simulating irrigation practices on N release from the applied FYM with different C:N ratios.

1.3- OBJECTIVES:

This study consists of a pot experiment, which was a repeat of the previous pot experiment (Chapter 3) but with some modifications. The modifications involved a change in the FYM application rates and the addition of urea. They were made to

allow an investigation of N transformation progressing from the applied FYM with different C:N ratios and higher rates than those used in the previous pot experiment.

The objectives of this study are:

1- To examine the effects of intermittent wetting-drying conditions on N transformation.

2- To investigate the effects of different C:N ratios on N transformations under different moisture conditions.

2- EXPERIMENTAL DESIGN:

In this pot experiment, microbial N mineralisation from four FYM application rates and three wetting-drying cycles were investigated under controlled temperature at 20°C. The FYM rates used were equivalent to 0, 20, 40, and 80 t ha^{-1} (Y0, Y1, Y2, and Y3, respectively), which were modified from the 0, 20, 30, and 40 t ha^{-1} used in the previous pot experiment (Section 2, Chapter 3).

Urea (46% N) was applied to all samples at a rate equivalent to 300 kg N ha^{-1}. This rate was chosen to mimic the rate of N fertilizer used in the KSA for wheat in Al-Gassim area (Gassim Agricultural Company (GAC), 1987).

Three wetting-drying cycles (wetting treatments) were adopted in this experiment similar to the previous pot experiment (Section 2, Chapter 3). They were achieved by applying water every 2, 4, or 6 days (M1, M2, and M3, respectively). The combination of the FYM-wetting treatments is summarised in Table 4.1. Three replicates were used for each FYM-wetting treatment.

Table 4.1. The combination of the FYM-wetting treatments used in the study.

Wetting		FYM treatments			
treatments	interval	Y0	Y1	Y2	Y3
	(day)	0 t ha^{-1}	20 t ha^{-1}	40 t ha^{-1}	80 t ha^{-1}
M1	2	Y0M1	Y1M1	Y2M1	Y3M1
M2	4	Y0M2	Y1M2	Y2M2	Y3M2
M3	6	Y0M3	Y1M3	Y2M3	Y3M3

The experiment commenced on April 24 1995 and was completed on June 17 1995. This period was expected to be sufficient to obtain enough data about primary N mineralisation, which occurs largely in the first 10 days as shown in the previous pot experiment (Chapter 3). The period was however extended to provide an incubation period comparable to all the wetting treatments, thus they would be started and terminated on the same dates.

3- MATERIALS AND EXPERIMENTAL PROCEDURE:

3.1- MATERIALS:

The materials used in this experiment were: FYM with a C:N ratio of 18.94 (Section 2, Chapter 3), urea (46% N), un-modified sand, plastic pots (0.5 *l* Capacity), woven steel mesh, scotch brite, balance (Sartorius 1507, capacity 5500 gm ± 10 mg), Technicon Auto-Analyzer II, Buchi equipment, flame photometer, EC meter, pH meter, and distilled water.

3.2- EXPERIMENTAL PROCEDURE:

36 pots were used in this experiment. As indicated in the previous pot experiment (Section 3.2, Chapter 3), each pot was prepared individually by mixing the corresponding weight of the applied FYM with 500 gm of un-modified sand.

The mixture was then placed in a pot containing a woven steel mesh and scotch brite on the bottom. The mesh and the brite were used to prevent mixture loss while allowing free drainage from the bottom of the pot. Urea was then incorporated into the surface of the mixture. The weights of the FYM and urea used for every FYM treatment are summarized in Table 4.2.

Water was applied every 2, 4, or 6 days (Section 2). The volume of water applied to each pot was a total of two water quantities. One quantity was equal to the water retained in the sample prior to water application. This was determined on a basis of weight differences. The other quantity was equal to the average water quantity needed to bring each FYM treatment to FC.

This average water quantity was determined in the first wetting event. The event was undertaken by applying 250 ml of water to each pot, which was already prepared and weighed. Water was then allowed to drain freely from the bottom of the pot. After the drainage stopped, the pot was re-weighed and water needed to bring the pot to FC was calculated.

Table 4.2. Summary of the weights of FYM and urea applied to each pot.

Treatments	Applied FYM		Applied urea	
	(gm pot^{-1})	(t ha^{-1})	(gm pot^{-1})	(kg N ha^{-1})
Y0	0.00	0	0.13	300
Y1	3.85	20	0.13	300
Y2	7.70	40	0.13	300
Y3	15.40	80	0.13	300

The average water quantity was then calculated for the nine replicates included in each FYM treatment (3 wetting treatments X 3 replicates). This was done to minimise variations in volumes of water applied to the replicates of each FYM treatment to bring them to FC. The summary of the average water quantity needed to bring each FYM treatment to FC is outlined in Table 4.3.

Table 4.3. Average water quantity needed to bring each FYM treatment to FC.

FYM treatment	Water quantity		
	average (ml)	S.D. (ml)	C.V. (%)
Y0	115	1.62	1.40
Y1	119	0.89	0.70
Y2	124	2.32	1.90
Y3	143	3.02	2.10

N.B.: S.D. and C.V. refer to standard deviation and coefficient of variations.

The samples were randomly distributed on a table placed in a temperature controlled room at 20°C. The room is located in the Post-Harvest Technology Department, Silsoe College, Cranfield University.

As indicated in the previous pot experiment (Chapter 3), in every wetting event excess water was allowed to drain freely from the bottom of the pots. Effluent samples as time series were then collected from the pots as they were watered. These samples were then preserved with mercuric chloride (40 mg Hg Cl_2 l^{-1}) given a final concentration of 1 ml of Hg Cl_2 solution per 100 ml of effluent sample. The preserved samples were then stored at 4°C (Allen, 1989).

A bulked sample was made for every replicate by accumulating 5 ml of the preserved time series samples collected. The bulked samples were then stored at 4°C.

Both the time series and bulked samples were analyzed for nitrate (NO_3^--N) and ammonium (NH_4^+-N) using a Technicon Auto-Analyzer II. Total soluble nitrogen (TSN) was determined in both samples by the autoclave method (Williams, ***et al.***, 1995).

After the experiment ceased, soil samples were analyzed for total nitrogen (TN) using a Buchi equipment (Digestion Unit 435, Distillation Unit B316, and Scrubber Unit 412).

Total soluble salts (EC) and acidity (pH) were only determined in the time series samples using Jenway 4070 and Camlab CG837 probes, respectively. The EC values are expressed in dS m^{-1}.

The effluent samples collected in the first four wetting events were also analyzed for calcium (Ca^{2+}) and magnesium (Mg^{+2}) by the EDTA titration method (Rump & Krist, 1992), sodium (Na^+) and potassium (K^+) using a flame photometer (Corning 400) (Rump & Krist, 1992), and chloride (Cl^-) using the Technicon Auto-Analyzer II.

All the details of the analytical methods used in this experiment are outlined in Appendix A-1.

4- RESULTS AND DISCUSSION:

This pot experiment was designed to examine the effects of intermittent wet-dry conditions on the microbial mineralisation of N from the applied FYM with different C:N ratios (Section 1.3.3).

The objective of this section is to discuss the results obtained from this experiment. The discussion comprises:

1- C:N ratios of the FYM treatments.

2- Strategy of water application.

3- N results.

4- Soluble salts and acidity.

4.1- C:N RATIOS OF THE FYM TREATMENTS:

It has been already indicated in Section 3.2 that in this experiment different application rates of FYM with a rate of urea were used resulting in different FYM treatments with different C:N ratios. The FYM used contained 49.80% organic carbon (OC) and 2.63% total nitrogen (TN) (Table 3.1, Chapter 3).

This section aims to discuss the different C:N ratios of the FYM treatments adopted. The discussion is as follows:

The amounts of OC and TN applied from the FYM and urea to each FYM treatment are summarised in Table 4.4. The table also includes the different C:N ratios calculated for the FYM treatments.

Table 4.4. Summary of C:N ratios of the FYM treatments adopted.

FYM treatments	OC applied			TN applied			C:N ratio
	FYM	urea	total	FYM	urea	total	
	(mg pot^{-1})			(mg pot^{-1})			
Y0	0.00	26.00	26.00	0.00	59.80	59.80	0.83
Y1	1917.30	26.00	1943.30	101.26	59.80	161.06	12.07
Y2	3834.60	26.00	3860.60	202.51	59.80	262.31	14.72
Y3	7669.20	26.00	7695.20	405.02	59.80	464.82	16.56

Table 4.4 shows that the C:N ratios of the FYM treatments are within the range in which the net N mineralisation is likely. Different investigators have suggested that a

C:N ratio of 25:1 or less is the critical range within which net N mineralisation occurs (Black; 1984; Haynes, 1986a; Tisdale, ***et al.***, 1990; Archer, 1988; Barber, 1995).

It can be concluded that the plan of this experiment to adopt different C:N ratios for the FYM treatments was achieved. The C:N ratios of the different FYM treatments were within the range where N release is likely.

4.2- STRATEGY OF WATER APPLICATION:

As indicated earlier (Section 3.2), water was applied every 2, 4, or 6 days using a strategy designed to minimise variations in volumes of water applied to the replicates of each FYM treatment.

This section discusses the water application strategy adopted in this pot experiment under the following headlines:

1- Variations in water applied.

2- Moisture conditions prior to water application.

4.2.1- Variations in water application:

The strategy of water application resulted in different wetting events varying in numbers and volumes of water applied to each FYM treatment. The water application events are summarised in Table 4.5. Tables 4.6, 4.7, and 4.8 show the different volumes of water applied to each FYM treatment at each wetting event for the M1, M2, and M3 treatments, respectively.

Tables 4.6, 4.7, and 4.8 show that variations in volumes of water applied to each FYM treatment at any wetting event were small. The percentages of coefficient of variations (C.V.%) were generally less than 7%. This implies that the wetting strategy was successful in minimising variations in water application between the replicates of each treatment.

Tables 4.6, 4.7, and 4.8 also show that the volumes of water applied at any event decreased with the decrease in the FYM application rates or the wetting frequencies, as a result of the water application strategy adopted. This suggests that the different volumes of water applied caused differences in the soil moisture conditions between

the FYM-wetting treatments. The different moisture conditions are discussed in the following section.

Table 4.5. Summary of the water application events (☆) for the wetting treatments.

Month	May				June								
Day	24	26	28	30	1	3	5	7	9	11	13	15	17
M1	☆	☆	☆	☆	☆	☆	☆	☆	☆	☆	☆	☆	☆
M2	☆		☆		☆		☆		☆		☆		☆
M3	☆			☆			☆			☆			☆

Table 4.6. Average volumes of water applied to each FYM treatment at every wetting event for the M1 treatment.

Date	FYM treatments							
	Y0		Y1		Y2		Y3	
	Volume (ml)	C.V. (%)	Volume (ml)	C.V. (%)	Volume (ml)	C.V. (%)	Volume (ml)	C.V. (%)
24 May	250	0.00	250	0.00	250	0.00	250	0.00
26 May	244	0.41	255	0.78	266	1.88	306	0.65
28 May	207	0.00	220	0.91	234	1.71	275	2.55
30 May	210	0.48	223	1.35	239	1.67	276	3.62
1 June	211	0.47	228	1.75	243	1.65	280	2.86
3 June	208	1.44	226	1.77	238	1.26	275	3.27
5 June	209	0.96	225	1.78	239	1.67	276	2.90
7 June	210	1.43	227	1.76	241	1.24	278	3.24
9 June	210	0.43	226	1.77	240	1.67	276	2.90
11 June	208	0.96	224	1.34	238	1.68	276	2.90
13 June	207	0.97	225	2.22	239	1.67	274	4.01
15 June	208	1.44	225	2.22	238	1.68	276	3.99
17 June	206	0.97	224	1.79	239	2.09	275	3.27
Total	2788	0.39	2978	1.38	3144	2.99	3593	2.73

N.B.: C.V.% refers to coefficient of variation.

Table 4.7. Average volumes of water applied to each FYM treatment at every wetting event for the M2 treatment.

Date	FYM treatments							
	Y0		Y1		Y2		Y3	
	Volume (ml)	C.V. (%)	Volume (ml)	C.V. (%)	Volume (ml)	C.V. (%)	Volume (ml)	C.V. (%)
24 May	250	0.00	250	0.00	250	0.00	250	0.00
28 May	199	1.01	201	3.48	214	2.38	249	2.81
1 June	201	0.50	205	3.85	218	3.67	261	6.51
5 June	195	0.51	203	4.93	215	5.12	252	1.98
9 June	197	0.51	203	4.43	217	5.53	253	1.98
13 June	192	1.04	199	5.03	213	6.10	249	2.91
17 June	192	0.52	200	5.00	213	6.57	249	2.91
Total	1426	0.21	1461	3.69	1540	4.09	1763	2.61

N.B.: C.V.% refers to coefficient of variation.

Table 4.8. Average volumes of water applied to each FYM treatment at every wetting event for the M3 treatment.

Date	FYM treatments							
	Y0		Y1		Y2		Y3	
	Volume (ml)	C.V. (%)	Volume (ml)	C.V. (%)	Volume (ml)	C.V. (%)	Volume (ml)	C.V. (%)
24 May	250	0.00	250	0.00	250	0.00	250	0.00
30 May	179	2.79	184	4.89	195	3.59	241	1.24
5 June	178	1.12	182	2.20	196	4.59	245	0.82
11 June	176	1.14	180	3.33	197	5.08	244	1.23
17 June	168	1.79	174	2.30	190	5.26	240	0.83
Total	951	1.19	970	2.28	1028	3.47	1220	0.74

N.B.: C.V.% refers to coefficient of variation.

4.2.2- Moisture conditions prior to water application:

Water content prior to and after water application was calculated on basis of dry weight of the pots. The results of the calculation are shown in Figures A-4.1 to A-4.6 in Appendix A-4. The figures show that for all the wetting treatments the moisture conditions prior to or after water application were generally constant throughout the experiment. The summary of range and average of water content for the FYM-wetting treatments prior to and after water application is shown in Table 4.9.

Table 4.9. Summary of range and average of water content prior to and after water application for the FYM-wetting treatments.

Treatmen		Moisture values (%)			
Wetting	FYM	Prior to water application		After water application	
		range	average	range	average
M1	Y0	18.21-19.69	18.78	21.61-22.87	21.93
	Y1	20.03-21.51	20.95	23.59-24.07	23.83
	Y2	21.38-23.46	22.50	24.62-26.05	25.75
	Y3	24.76-26.59	25.70	28.38-29.54	29.16
M2	Y0	15.33-16.81	16.24	21.21-22.97	21.89
	Y1	15.89-17.13	16.47	22.94-23.69	23.16
	Y2	17.44-18.47	17.91	26.65-24.42	23.91
	Y3	20.50-21.65	20.99	27.11-27.35	27.29
M3	Y0	10.75-13.41	12.27	20.47-23.30	21.49
	Y1	10.75-12.48	11.91	21.82-23.63	22.37
	Y2	13.64-14.85	14.31	22.42-23.98	23.24
	Y3	18.52-19.60	19.03	25.77-27.62	27.12

Table 4.9 shows that moisture conditions prior to water application differed between the FYM treatments and the wetting treatments, as planned. The highest water content was found for the Y3 treatment and decreased as the FYM application rates declined. For the wetting treatments, moisture conditions also decreased as the

wetting frequencies decreased. This shows that the applied FYM was subjected to different soil moisture conditions.

It can be concluded that variations in water application between the replicates of each FYM-wetting treatment were small. The FYM-wetting treatments had different moisture conditions, suggesting that the amount of N to be released from the applied FYM may differ as results of the differences in the FYM application rates and the wetting regimes adopted.

4.3- N RESULTS.

As already indicated (Section 3.2), NO_3^--N, NH_4^+-N, and TSN were determined in the effluent as time series and bulked samples.

The objective of this section is to discuss the results of these determinations. The discussion is undertaken in the following manners:

1- NH_4^+-N Leached.

2- NO_3^--N Leached.

3- N in the effluent.

4- N budgets.

4.3.1- NH_4^+-N Leached:

Figures 4.1.a, 4.1.b, and 4.1.c show the NH_4^+-N results in the effluent samples recovered from the different FYM application rates under the M1, M2, and M3, respectively.

The figures show that the maximum amount of NH_4^+-N mineralised occurred in the first three wetting events, which agrees with the values of NH_4^+-N peak observed in the previous pot experiment (Section 4.2.1, Chapter 3). This indicates that the planned incubation period for this experiment (Section 2) was sufficiently long enough to observe the primary N mineralisation.

Figures 4.1.a, 4.1.b, and 4.1.c also show that the values of NH_4^+-N peak increased as the moisture conditions increased. The values of NH_4^+-N peak and $LSD_{0.05}$ for the FYM-wetting treatments are summarised in Table 4.10.

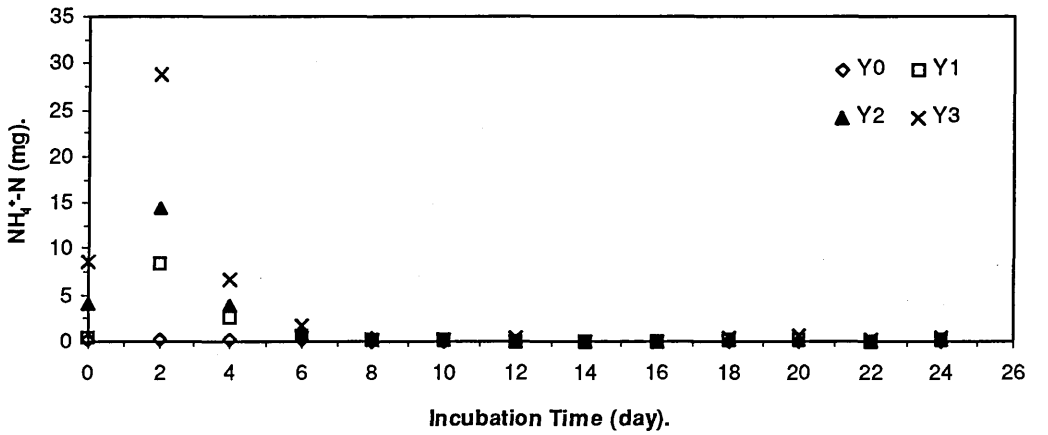


Figure 4.1.a. NH_4^+-N recovered from the different FYM rates under the M1 treatment.

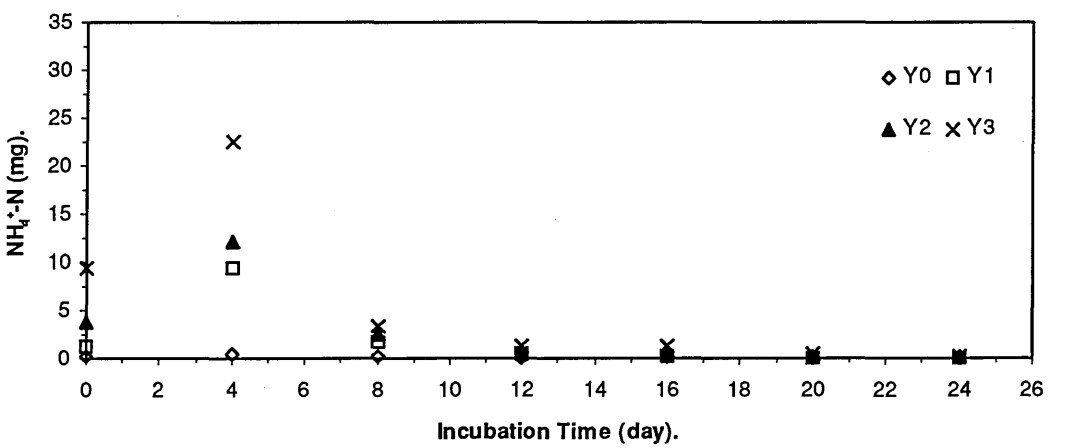


Figure 4.1.b. NH_4^+-N recovered from the different FYM rates under the M2 treatment.

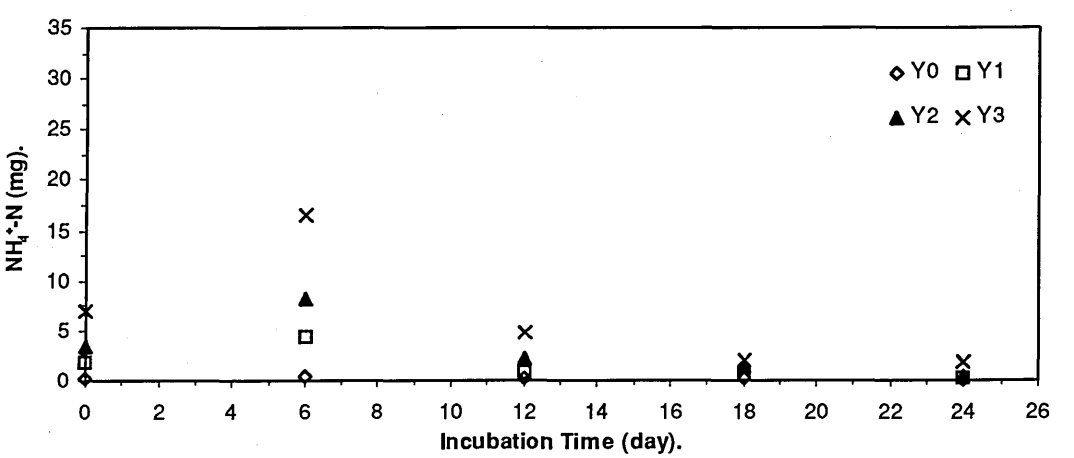


Figure 4.1.c. NH_4^+-N recovered from the different FYM rates under the M3 treatment.

Table 4.10. The values of NH_4^+-N peak (mg) of the different FYM-wetting treatments.

Treatments	Y0	Y1	Y2	Y3	$LSD_{0.05}$
M1	0.19	8.46	14.47	28.84	6.47
M2	0.38	9.42	12.00	22.48	5.36
M3	0.37	4.41	8.11	16.57	4.10
$LSD_{0.05}$	0.06	2.52	4.02	N.S.	

N.B.: N.S. refers to not significantly different.

For each wetting treatment, Table 4.10 shows that the values of NH_4^+-N peak were significantly different (P = 0.05) between the FYM application rates. The Y0 treatment was significantly smaller than the other FYM treated samples. The Y3 treatment was markedly greater than the other treatments. Differences between the Y1 and Y2 treatments were however not significant. This is due to differences in the amount of N applied (Table 4.4).

For each FYM treatment, Table 4.10 shows that there were also significant differences in the values of NH_4^+-N peak between the different moisture conditions. However, these differences were less marked than those caused by the different application rates, which is in contrast to the findings of the previous experiment where it was observed that the moisture conditions had a greater effect on N mineralisation than the FYM application rates (Section 4.2.1, Chapter 3).

This is deduced to be a result of urea application, which narrowed the C:N ratios of the different FYM application rates increasing the N mineralised from the applied FYM. Urea is also known for its rapid hydrolysis (Delaune & Patrick, 1970; Antil, ***et al.***, 1992), which is further accelerated by the addition of organic materials (Delaune & Patrick, 1970). Such rapid hydrolysis may have accentuated differences in NH_4^+-N mineralised between the different FYM application rates.

Table 4.10 also shows that under the different wetting treatments the amount of N mineralised from the Y3 treatment was not significantly different. This is attributed to the close values of moisture content between the wetting treatments (Table 4.9),

resulting from the high application rate of FYM (Salter & Williams, 1963, quoted by Hall & Coker, 1981).

Stanford & Epstein (1974) indicated that in a range of moisture content from optimum (0.33 to 0.10 bar) to 15 bar, a near-linear relationship generally existed between amount of mineral N accumulation and soil water content.

This leads us to conclude that the application of urea lessened the effects of moisture on N mineralisation compared with those by application rates of FYM, which at the high rate (80 t ha^{-1}) reduced differences in moisture conditions between the drying intervals studied, causing the amounts of N mineralised by the micro-organisms not to be significantly different.

4.3.2- NO_3^--N Leached:

The NO_3^--N results (mg) recovered in the effluent collected from the different FYM application rates under the M1, M2, and M3 treatments are shown in Figures 4.2.a, 4.2.b, and 4.2.c, respectively.

Figures 4.1.a, 4.1.b, and 4.1.c show that the NO_3^--N values were generally small being less than 0.1 mg for all the FYM-wetting treatments. The figures also show that the values had no consistent trend for the FYM or wetting treatments. These small and inconsistent values agree with the NO_3^--N results observed in the previous pot experiment (Section 4.2.2, Chapter 3), confirming the lack of nitrification in the FYM-sand mixture deduced.

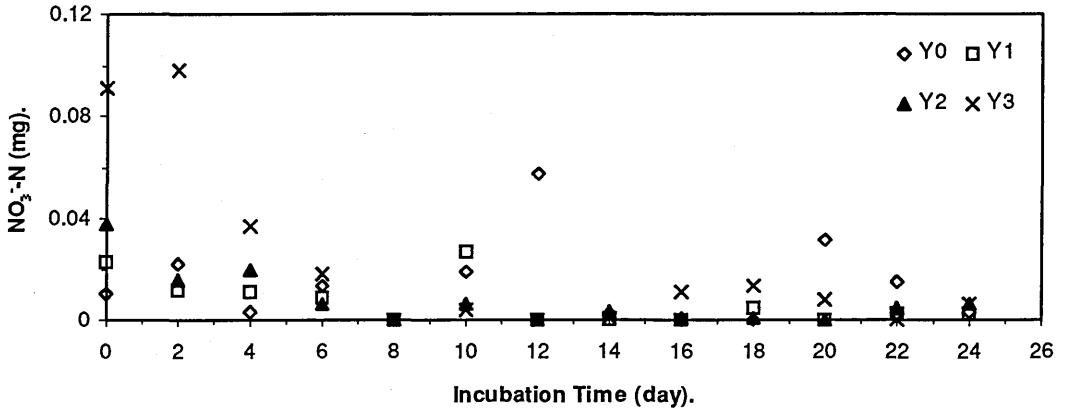


Figure 4.2.a. NO_3^--N recovered from the different FYM rates under the M1 treatment.

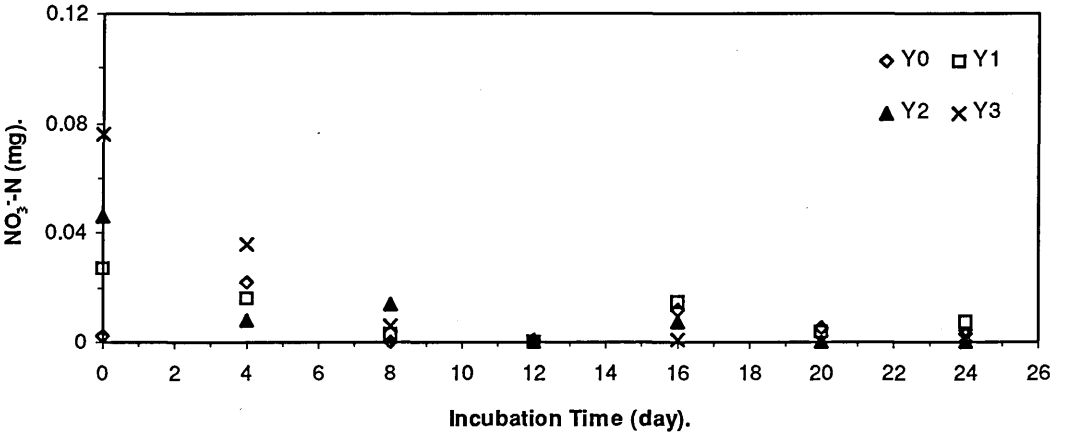


Figure 4.2.b. NO_3^--N recovered from the different FYM rates under the M2 treatment.

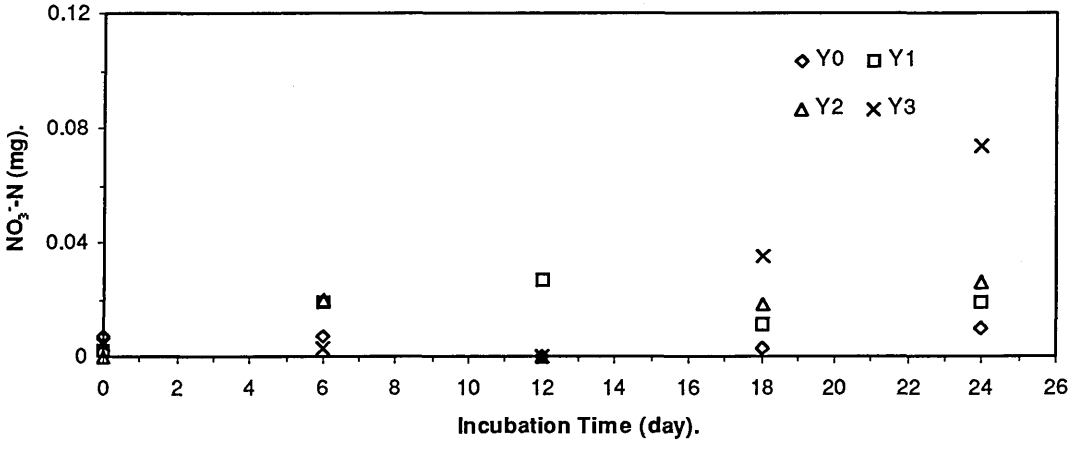


Figure 4.2.c. NO_3^--N recovered from the different FYM rates under the M3 treatment.

4.3.3- N in the effluent:

The mass values of NH_4^+-N, NO_3^--N, and TSN (mg) determined in the effluent as time series and bulked samples are shown in Table 4.11.

Table 4.11. Summary of N recovered in the effluent samples collected.

Treatments		NH_4^+-N		NO_3^--N		TSN	
		time series	bulked	time series	bulked	time series	bulked
Wetting	FYM	(mg)					
M1	Y0	1.33	1.43	0.18	0.12	45.53	44.50
	Y1	13.27	13.47	0.09	0.03	118.36	121.10
	Y2	24.86	23.86	0.10	0.09	153.36	155.20
	Y3	48.62	47.40	0.29	0.16	208.06	206.40
M2	Y0	1.15	1.17	0.05	0.01	41.83	42.60
	Y1	12.81	11.71	0.07	0.05	92.41	91.30
	Y2	19.17	18.23	0.08	0.04	127.27	126.40
	Y3	38.32	38.49	0.12	0.06	190.00	188.00
M3	Y0	0.94	1.00	0.03	0.04	38.94	38.60
	Y1	7.75	7.26	0.08	0.08	78.88	79.90
	Y2	15.41	14.11	0.06	0.02	113.70	115.40
	Y3	32.16	33.22	0.12	0.05	167.02	166.60

Table 4.11 shows that the values of NH_4^+-N and TSN for both time series and bulked samples increased as moisture conditions increased, agreeing with the relationship observed between the values of NH_4^+-N peak and the moisture conditions (Section 4.3.1). This demonstrates the effects of moisture conditions on N leaching in agreement with the findings of other investigators, as already indicated in the previous pot experiment (Sections 4.2.1 and 4.2.3, Chapter 3).

Differences in the NH_4^+-N values between the time series and bulked samples were generally small (Table 4.11). This indicates that chemical preservation minimised the variations between both samples, as suggested in the previous pot experiment (Section 4.2.3, Chapter 3).

Table 4.11 also shows that the amount of NH_4^+-N mineralised increased as the FYM application rates increased. Under all the wetting treatments adopted, the amount of NH_4^+-N mineralised from the Y3 treatment was double the amount mineralised from the Y2 treatment, which was approximately twice as high as the amount mineralised from the Y1 treatment. This suggests that the amounts of N mineralised increased as the application rates of FYM were increased to levels beyond those used in the previous pot experiment.

4.3.4- N budgets:

Soil samples were analyzed for TN after the experiment was ceased, as previously outlined in Section 3.2. The analysis was done to calculate the N budget, which was completed as in the previous pot experiment (Section 4.2.4, Chapter 3).

Calculations of N budgets for the applied FYM under the different wetting treatments are summarised in Table 4.12.

Table 4.12. N budgets for the different FYM-wetting treatments.

Treatments		TN (mg)		N recovered	N not-accounted for	
Wetting	FYM	at the start	at the end	(mg)	(mg)	(%)
M1	Y0	59.80	12.99	44.50	2.31	3.86
	Y1	161.06	31.43	121.10	8.53	5.29
	Y2	262.31	85.12	155.20	21.99	8.38
	Y3	464.82	189.27	206.40	69.15	14.88
M2	Y0	59.80	14.25	42.60	2.95	4.94
	Y1	161.06	59.48	91.30	10.28	6.38
	Y2	262.31	106.78	126.40	29.13	11.10
	Y3	464.82	193.01	188.00	83.81	18.03
M3	Y0	59.80	18.11	38.60	3.09	5.17
	Y1	161.06	66.33	79.90	14.83	9.21
	Y2	262.31	107.02	115.40	39.89	15.21
	Y3	464.82	198.42	166.60	99.80	21.47

Table 4.12 shows that the percentages of N not-accounted for increased as the FYM application rates increased. The percentages were also higher than those calculated in the previous pot experiment (Section 4.2.4, Chapter 3). This is explained by the increase in pH, as will be seen later (Section 4.4.3).

4.3.5- Effect of different C:N ratios on N mineralisation:

As already indicated (Section 1.3), this experiment aimed to study the effects of different C:N ratios on microbial mineralisation of N from the applied FYM under different wetting conditions.

This experiment was a repeat of the previous pot experiment with a modification in the range of FYM application rates with the addition of urea (Section 1.3). These modifications resulted in different C:N ratios for the FYM treatments (Table 4.4).

This section aims to discuss the effects of the C:N ratios on N mineralisation. The discussion compares the amounts of NH_4^+-N mineralised from the common FYM application rates (20 and 40 t ha^{-1}) used below the previous pot experiment with no urea applied and this experiment with urea applied.

The different C:N ratios of the common FYM application rates used in both experiments are summarised in Table 4.13. The Table shows that all the C:N ratios are lower than 25:1 ratio, the critical value below

which net N mineralisation is likely (See Section 4.1).

Table 4.13. The values of C:N ratios of the common FYM application rates used in both the previous and the current pot experiments.

FYM application rates	20 (t ha^{-1})		40 (t ha^{-1})	
Experiments	Previous	Current	Previous	Current
C:N ratio	18.93	12.07	18.93	14.72

For the different wetting regimes adopted, the amounts (mg) and percentages (%) of NH_4^+-N mineralised which were recovered in the effluent from the two FYM application rates used in both experiments are summarised in Table 4.14. The amounts are the total NH_4^+-N recovered in the time series samples for the previous experiment

(Section 4.2.3, Chapter 3) and for this experiment (Section 4.3.3). The percentages are calculated on the basis of total N applied for each FYM treatment.

Table 4.14. Amounts and percentages of NH_4^+-N mineralised from both application rates used in the previous and current experiments.

Wettings Treatments	FYM application rates (t ha^{-1})							
	20				40			
	previous		current		previous		current	
	(mg)	(%)	(mg)	(%)	(mg)	(%)	(mg)	(%)
M1	9.59	9.47	13.27	8.24	16.99	8.39	24.86	9.48
M2	5.53	5.46	12.81	7.95	9.69	4.78	19.17	7.31
M3	3.01	2.97	7.75	4.81	6.96	3.44	15.41	5.87

Table 4.14 shows that the percentages of NH_4^+-N recovered are generally higher in the current experiment than the previous experiment. The only exception to such a general observation is the percentages for the 20 t FYM ha^{-1} under the M1 treatment, which is explained in part by differences in the values of N not accounted for between both experiments (See Sections 4.2.4 and 4.3.4 of Chapters Three and Four, respectively), and by the frequent water application for the M1 treatment that possibly caused leaching losses for the substrate required by the micro-organisms responsible for the microbial transformation of N.

The increase in percentages of NH_4^+-N recovered was a result of the application of urea in the current experiment narrowing the C:N ratios and enhancing the process of N mineralisation. This agrees with the suggestions of other investigators who indicated that additions of N fertiliser stimulate net mineralisation of soil N (Alexander, 1977; Jansson & Person, 1982).

Differences between the percentages of NH_4^+-N recovered as a result of the different C:N ratios are relatively small (Table 4.14). These effects are better shown by the percentages rate of increase in the amounts of NH_4^+-N recovered from the two FYM application rates used in both experiments (Table 4.15).

The percentages rate of increase in the amounts of NH_4^+-N recovered were generally higher for the 20 t FYM ha^{-1} than for the 40 t FYM ha^{-1}, as seen from differences between the averages of percentages rate (Table 4.15). This shows that urea application increased N mineralisation from the decomposing materials with a narrow C:N ratio more than from the materials with a wide C:N ratio.

Table 4.15. The percentages (%) rate of increase in the amounts of NH_4^+-N recovered from the two experiments for FYM treated samples only.

Application Rates	Percentages rate of increase (%)			
(t ha^{-1})	M1	M2	M3	Average
20	38	132	157	87
40	46	98	121	77

Table 4.15 also shows that the percentages rate of increase in the amounts of NH_4^+-N mineralised increased as the drying conditions increased following an order of M3 > M2 > M1. This suggests that narrowing the C:N ratios of the decomposing materials by urea application has a greater effect on N mineralisation in dry conditions than in wet conditions.

In conclusion, narrowing the C:N ratios of the FYM application rates by urea addition increased the amounts of NH_4^+-N mineralised from the FYM applied. This agrees with the conclusion drawn in section 4.3.1 where it was shown that the effects of moisture conditions on N mineralisation were reduced by urea application, whilst effects of FYM application rates were increased.

4.4- SOLUBLE SALTS AND ACIDITY:

EC and pH were determined in the effluent samples as time series, as already outlined in Section 3.2. Also, the effluent samples collected in the first four wetting events were analyzed for some specific ions (Ca^{2+}, Mg^{+2}, Na^+, K^+, and Cl^-). The objective of this section is to discuss the results of these analyses, covering the following topics:

1- Results of salinity.

2- Results of pH.

4.4.1- Soluble salts:

Salinity is examined by the effects of osmotic potential (OP) and specific ion toxicity exerted on micro-organisms (Wood, 1989).

The values of total soluble salts determined as EC (dS m^{-1}) are outlined in figures 4.3a, 4.3b, and 4.3c for the M1, M2, and M3 treatments, respectively. The figures show that the maximum EC values occurred in the second wetting events, with general patterns similar to the patterns observed for the values of NH_4^+-N (Section 4.3.1).

Figures 4.2.a, 4.3.b, and 4.3.c show that the EC values determined in this experiment were similar to the values found in the previous pot experiment (Section 4.3.1, Chapter 3). In this experiment, EC values were generally too small (less than 2.5 dS m^{-1}) to cause toxic inhibitory effects on micro-organisms responsible for N mineralisation. Using a model quoted by Bohn, ***et al.*** (1985), the corresponding osmotic potential to this EC value is approximately less than -0.8 bars, which is less than the value of osmotic potential that may prevent microbial activity (Hendrickson, ***et al.***, 1978; Makki, 1982; Wood, 1989).

Johnson & Guenzi (1963), quoted by Hendrickson, ***et al.*** (1978), suggested that increasing osmotic pressure from 0 to 30 bars in soil solution caused a nearly linear decrease in CO_2 evolution, an indication of microbial activity. Monagan & Barraclough (1992) indicated that nitrification was inhibited at 1 MPa (10 bar) osmotic potential, and at 2.6 MPa (26 bar) it was completely inhibited.

The concentrations (mg l^{-1}) of the specific ions analyzed in the effluent samples collected in the first four wetting events are shown in Tables 4.17, 4.18, and 4.19 for Na^+ and K^+, Ca^{2+} plus Mg^{2+}, and Cl^-, respectively.

Tables 4.16, 4.17, and 4.18 show that concentrations of these specific ions generally increased as the FYM application rates increased. This suggests that the FYM applied is an important source for these nutrients, which requires a good management to supply them in adequate quantities to plants.

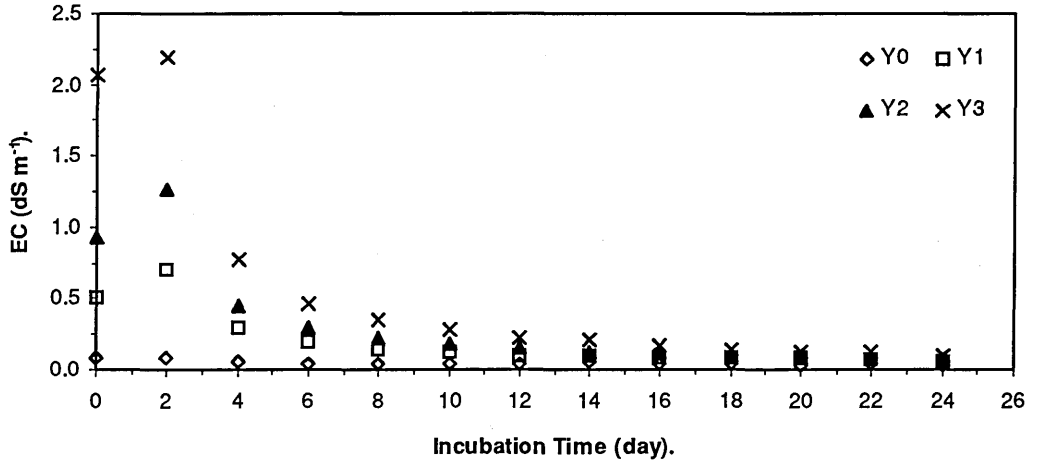


Figure 4.3.a. The EC values for the FYM application rates under the M1 treatment.

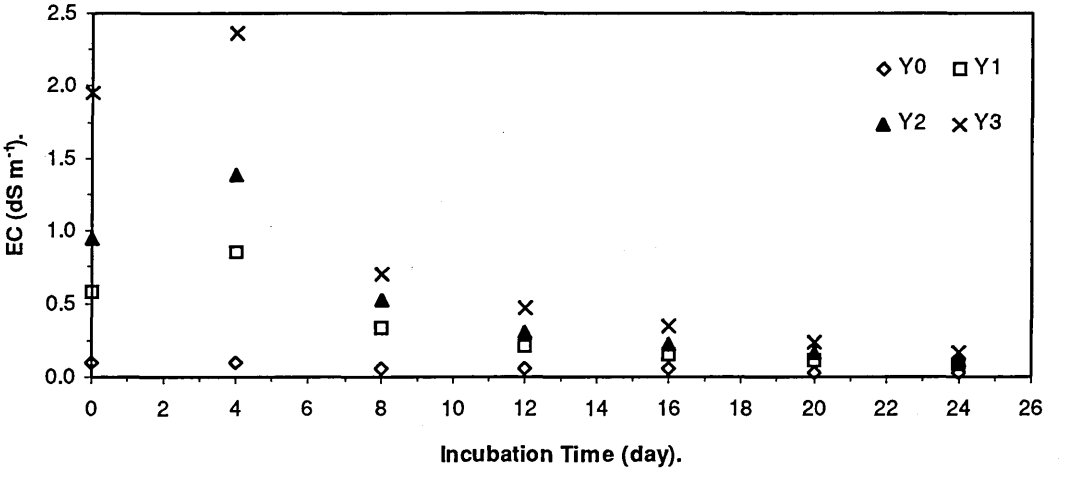


Figure 4.3.b. The EC values for the FYM application rates under the M2 treatment.

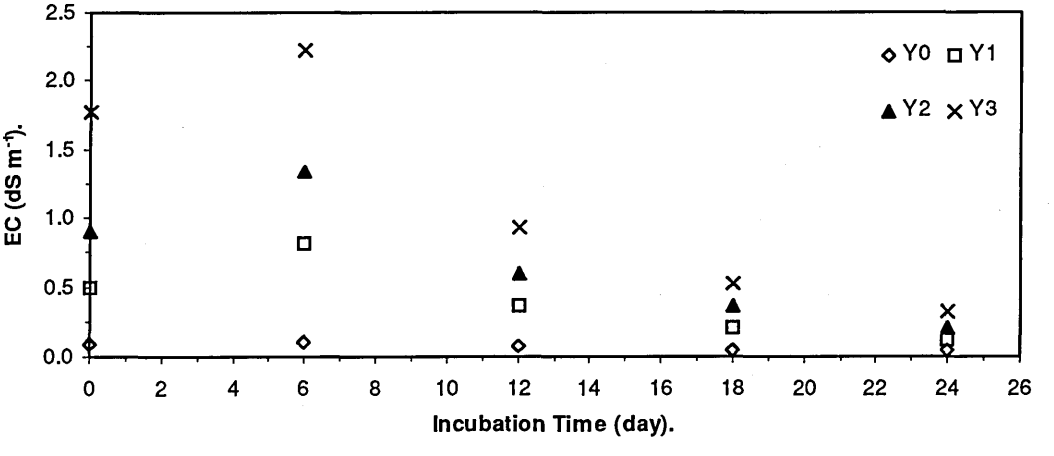


Figure 4.3.c. The EC values for the FYM application rates under the M3 treatment.

Table 4.16. Concentrations of Na^+ and K^+ (mg l^{-1}) in the time series effluent samples collected in the first four wetting events.

Wetting		FYM treatments							
treatments	events	Y0		Y1		Y2		Y3	
		Na^+	K^+	Na^+	K^+	Na^+	K^+	Na^+	K^+
M1	1	3.32	7.15	21.58	99.66	33.47	253.68	57.82	444.41
	2	3.32	4.29	17.15	98.70	34.99	251.77	50.79	385.28
	3	1.94	2.38	6.64	42.44	10.79	62.47	17.57	96.80
	4	1.66	1.43	2.49	21.93	4.43	33.86	6.09	50.54
M2	1	3.32	7.15	24.62	109.91	35.69	267.03	56.16	431.06
	2	4.15	5.72	25.59	105.62	39.28	274.66	55.19	411.99
	3	1.80	2.84	7.78	47.77	16.38	75.45	20.69	101.46
	4	1.66	1.43	3.73	25.99	6.92	43.15	9.96	61.27
M3	1	3.32	7.15	21.85	98.70	33.75	255.58	52.28	412.94
	2	4.84	5.72	29.46	110.63	41.22	281.33	56.16	411.03
	3	2.77	2.86	13.56	60.08	19.50	89.17	26.42	123.02
	4	2.21	2.43	7.33	37.43	10.51	56.74	12.73	74.39

Table 4.17. Concentrations of (Ca^{2+} + Mg^{2+}) (mg l^{-1}) in the time series effluent samples collected in the first four wetting events.

Wetting		FYM treatments			
treatments	events	Y0	Y1	Y2	Y3
M1	1	16.10	36.49	53.67	94.45
	2	15.03	92.31	163.15	274.77
	3	12.88	60.11	92.31	163.15
	4	13.95	47.23	85.87	150.27
M2	1	17.17	38.64	51.52	96.60
	2	18.25	118.07	208.23	343.47
	3	15.03	77.28	122.36	163.15
	4	8.59	47.23	77.28	130.95
M3	1	20.39	34.35	51.52	77.28
	2	17.17	105.19	135.24	392.84
	3	9.66	60.11	96.60	158.85
	4	6.44	45.08	83.72	109.48

Table 4.18. Concentrations of Cl^- (mg l^{-1}) in the time series effluent samples collected in the first four wetting events.

Wetting		FYM treatments			
Treatments	Events	Y0	Y1	Y2	Y3
M1	1	0.94	68.83	127.65	281.87
	2	1.25	33.81	68.27	138.97
	3	0.44	3.13	6.33	11.77
	4	2.20	3.11	4.36	8.14
M2	1	2.22	70.67	123.67	262.40
	2	0.77	34.57	85.18	159.47
	3	0.37	4.31	11.70	16.78
	4	0.37	1.58	3.45	5.43
M3	1	2.67	55.68	118.13	238.53
	2	5.24	47.16	87.48	167.75
	3	0.0	10.08	18.77	29.29
	4	0.06	3.48	6.10	7.37

The highest concentrations of Na^+ and K^+ (Table 4.16) and Cl^- (Table 4.18) occurred in the first wetting event, whereas Ca^{2+} + Mg^{2+} maximum concentrations occurred in the second wetting event (Table 4.17). These concentrations, however, are not expected to cause any inhibition to N mineralisation, as already discussed (See Section 3.2.5, Chapter One).

Thus it is concluded that the values of EC and specific ions observed were less than the reported concentrations that may induce inhibitory toxic effects on N mineralisation or nitrification. This agrees with the salinity results reported by Dale & Day (1966), who observed no retarding effects on microbial activity by salinity from by dairy cattle manure.

However, the results of soluble salts observed in this experiment as well in the previous experiment emphasize the need for a good management in agricultural activities during the first week after FYM application. The EC values and ions concentrations determined during this period may damage plant production. It has been shown that many salt tolerant plants are most sensitive at the emergence stage

(Carter, 1975; Maas & Hoffman, 1977; Makki, 1982; Wild, 1988; Ayers & Westcot, 1989; Wood, 1989; Rhoades, ***et al.***, 1992).

Also, lack of good management for the FYM applied may cause soil deterioration by salinity and associated problems (Tiarks, ***et al.***, 1974; Abbott, 1975). Abbott (1975) indicated that high soluble salts in manure, present as sodium and potassium, are capable of causing unfavorable soil structure, and can be toxic to plants in extremely high concentration.

4.4.2- Results of pH:

The pH values in the effluent samples collected from the different FYM application rates are shown in Figures 4.4.a, 4.4.b, and 4.4.c for the M1, M2, and M3 wetting treatments, respectively.

For all FYM treated samples, Figures 4.4.a, 4.4.b, and 4.4.c show that in the first wetting event pH values were the highest, being approximately 9 or more, thus very strongly alkaline (Brady, 1974). The pH then decreased to values within a range of 6.7 to 7.6, slightly acid to mild alkaline (Brady, 1974). These high values at the beginning of the experiment were a result of FYM decomposition and urea hydrolysis, both processes being known to increase the pH (Follett, ***et al.***, 1981; Schmidt, 1982; Tisdale, ***et al.***, 1990; Addiscott, ***et al.***, 1991; Killham, 1995). (For more details, see Section 3.2.4, Chapter 1).

Also, these high pH values suggest that appreciable amounts of NH_3 could have been volatilized (Miller & Donahue, 1995; Schmidt, 1982; Addiscott, ***et al.***, 1991), which explains the high values of N not-accounted for in this experiment (Table 4.12), compared to those observed in the previous pot experiment (Table 3.7, Chapter 3).

For the Y0 treatment, there were no clear peaks, with the pH values varying between 6.86 and 7.55, a neutral value of soil reaction (Brady, 1974). This suggests that urea was not hydrolyzed, which indicates that the un-modified sand used did not contain micro-organisms to carry out N mineralisation. Killham (1994) suggests that neutral pH value is the most favourable soil reaction for most soil bacteria.

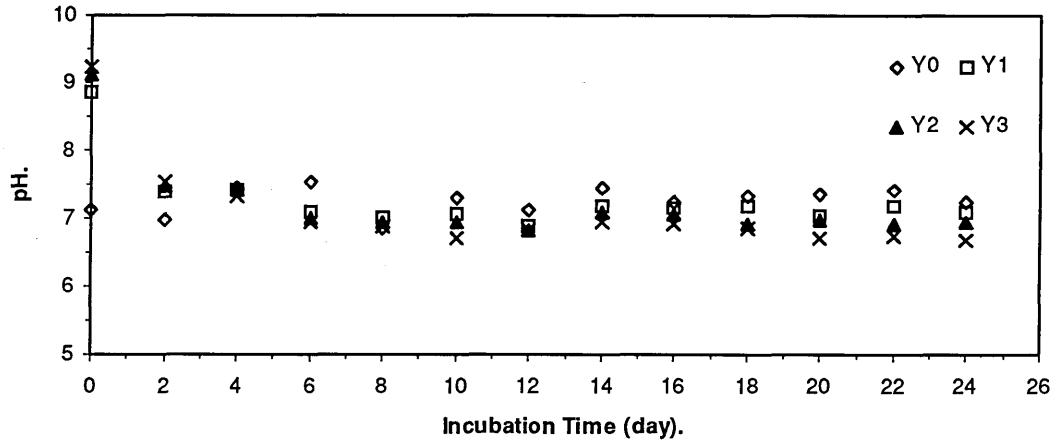


Figure 4.4.a. The pH values for the FYM application rates under the M1 treatment.

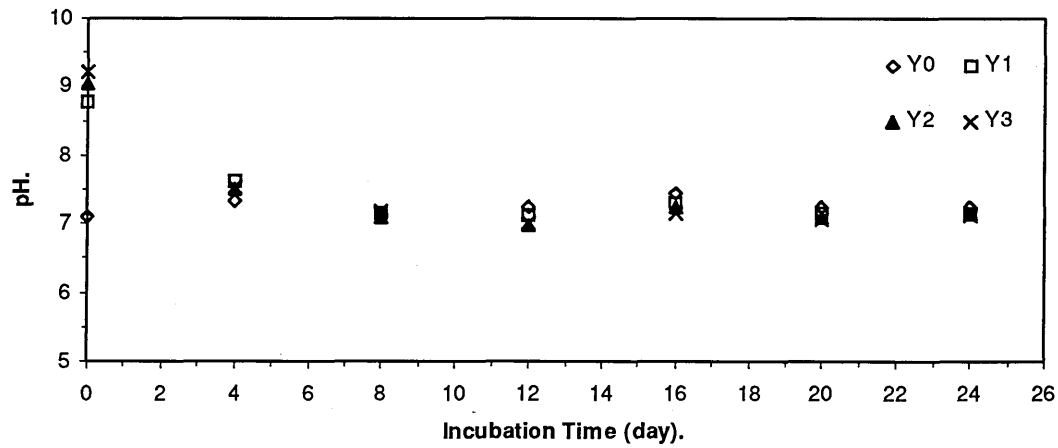


Figure 4.4.b. The pH values for the FYM application rates under the M2 treatment.

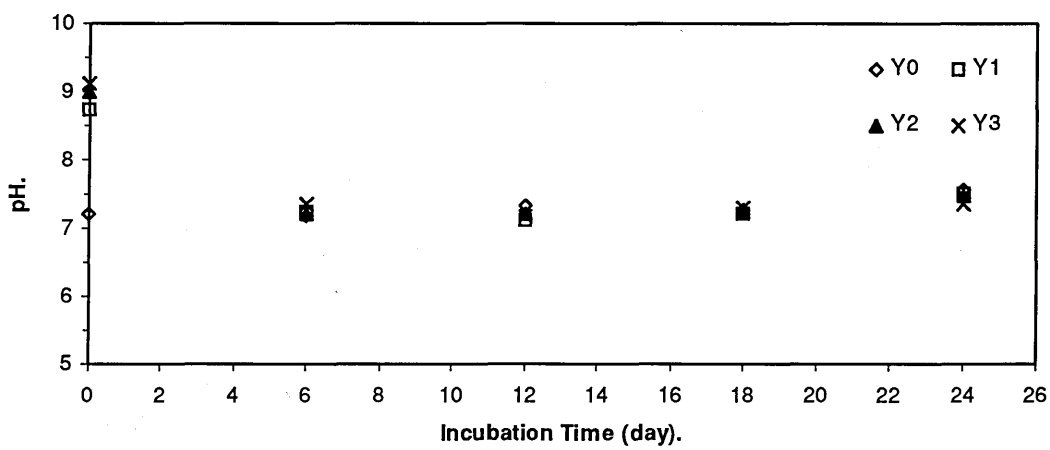


Figure 4.4.c. The pH values for the FYM application rates under the M3 treatment.

The lack of micro-organisms in the un-modified sand used explains the small values of NH_4^+-N mineralised recovered from the Y0 treatment under all the wetting conditions (Table 4.12).

5- CONCLUSIONS:

The following conclusions are drawn from this pot experiment:

1- Chemical preservation was effective in minimising the differences in the values of N forms between both the time series and bulked samples.

2- N mineralisation increased with higher FYM application rates, where they were higher than those in the previous pot experiment. For the wetting conditions adopted, the amounts of NH_4^+-N mineralised from the Y3 treatment (80 t ha^{-1}) were double the amounts mineralised from the Y2 treatment (40 t ha^{-1}), which were approximately twice as high the amounts mineralised from the Y1 treatment (20 t ha^{-1}).

3- Urea addition increased the amounts of N mineralised, as seen from differences in the percentages of mineralised N recovered in the effluent or in the percentage rate of increase in the amounts of N mineralised between the FYM application rates used in this and previous experiments.

4- The application of urea lessened the effects of moisture conditions compared with the application rates on N mineralisation, which suggests further investigation involving drier conditions is needed.

5- Lack of nitrifying bacteria in the FYM-sand mixture was also shown in this experiment, which supports the need for inoculating the mixture with a field soil to stimulate nitrification, as suggested in the previous pot experiment.

6- N results observed in this experiment and in the previous pot experiment showed that the values of TSN were higher than the values of NH_4^+-N mineralised. This indicates that a study using leaching columns to simulate a soil profile is needed. A leaching column experiment would enable us to mimic changes in the different forms of N released from the FYM applied at the surface when leached through a soil profile in a field condition.

7- The results of soluble salts and acidity observed in this experiment as well in the previous experiment emphasise the need for good management in agricultural activities involving the use of FYM. The management is expected to avoid plant damage and soil deterioration, that may consequently reduce the economical returns.

CHAPTER FIVE

EXPERIMENT THREE

THE EFFECTS OF DIFFERENT WETTING-DRYING REGIMES ON NITROGEN (N) TRANSFORMATIONS AND LEACHING IN SOIL COLUMNS.

1- INTRODUCTION:

The loss of nitrogen (N) from soil profiles through leaching is a major concern to farmers and to scientists who study the mechanisms of such loss. Agronomists for example consider it a loss of a vital nutrient which is required by growing plants, whilst environmentalists consider it a contaminant in the environment. N exists in the environment in several forms. One major form of N is mineralised from soil organic materials- whether they occur naturally in the soil or are applied to it. Nevertheless, farm-yard manure (FYM) application is practiced world-wide. This may be applied by farmers or be directly excreted onto soils by grazing animals.

The release of N from the applied FYM is affected by several factors, among which are moisture and temperature (Section 3.2, Chapter One). From previous experiments (Chapters 3 and 4), it was found that the major portion of mineralised N was released in the first wetting events. This suggests that temperature may vary within a narrow range in the field, during such a period. However, during the same period, moisture may vary widely in the field as a result of water application, whether by rainfall or irrigation. Irrigation is practiced predominantly in dry and warm conditions. Accordingly, in-between irrigations, moisture is probably the prevailing factor that controls the release of N from the applied FYM. In many irrigation practices in arid areas, some of the water applied at irrigation to growing crops is required for leaching purposes to leach salts in the soil profile so maintaining levels that are harmless to crops (As already discussed in Chapter One).

1.1- THE HYPOTHESIS:

It is hypothesised that variable soil moisture conditions resulting from different irrigation schedules affect the rate of N transformation from the applied FYM and hence the rate of N losses from the soil profile by leaching.

1.2- THE AIM:

This study aims to examine the effects of simulated centre pivot irrigation practices on N leaching losses released from applied organic materials (FYM) by microbial mineralisation under relatively warm conditions.

1.3- THE OBJECTIVES:

Two experiments have been conducted in this study. The first was a leaching column experiment in which FYM and urea mixed with soil were applied to the top of the soil columns. The second was a pot experiment that was divided into two studies, a farm-yard manure (FYM) and a urea study. The FYM study involved a mixture of FYM-soil with urea incorporated into the surface of the mixture. In the urea study, however, only the urea incorporated into the soil surface was used. Each experiment was done for the specific objectives outlined below:

1.3.1- Leaching column experiment:

The objectives of this experiment were:

1- To study the effects of different moisture regimes on the release and subsequent leaching of N from the applied FYM.
2- To examine the influence of simulated irrigation practices on the patterns of N leaching.
3- To examine the forms of N collected in the effluent leached from the soil column.

1.3.2- Pot experiment:

The objective of this experiment was to examine the nitrification process of N ammonified from the applied FYM and urea mixed with sand, inoculated by a field soil under different wetting conditions.

2- EXPERIMENTAL DESIGN:

This study was a continuation of the previous pot studies reported in Chapter Three and Chapter Four. In Chapter Three, the release of N from different application rates of FYM under different wetting strategies was studied. In Chapter Four, the effects of different carbon (C) to nitrogen (N) ratios (C:N) on the release of N from the applied FYM under different wetting schemes were studied. The different C:N ratios studied in Chapter Four were obtained by the addition of urea to the different rates of FYM applications. In this study the transformation of N from a fixed application rate of FYM with urea was investigated using leaching columns and pots.

The following aspects are discussed in this section:

1- The design of the leaching column and the pot experiments.

2- The arrangements of wetting treatments for both experiments.

3- The C:N ratio of the N sources used in the study.

2.1- THE DESIGN OF THE EXPERIMENTS:

The leaching column and pot experiments conducted in this study were designed as follows:

In the leaching column experiment, a total of twelve columns were used in the experiment. Each one was made of a PVC pipe, 0.10 m ID X 0.62 m long (Figure 5.1). The column consisted of two layers, a mixture layer and a sandy layer (Figure 5.1). In the mixture layer, an equivalent application rate of FYM (80 t FYM ha^{-1}) and urea (300 kg N ha^{-1}) with sand and field soil was used. The sandy layer was made of sand. The columns were constructed as follows:

The corresponding weight of the applied FYM rate (15.4 gm FYM) mixed with the sand (400 gm) and the sandy loam field soil (100 gm) was used in the top 0.04 m of the soil column. Urea (0.13 gm) was then incorporated into the surface of the mixture (the mixture layer). The sandy layer formed the remaining 0.57 m of the soil column. The mixted layer was individually prepared for each column.

The sandy layer was packed uniformly to a bulk density (ρ_b) of 1.50 gm cm^{-3}, air dry basis. Packing was completed by dividing the 0.57 m long layer into five equal sections. Then each section was filled with an adequate mass of sand to bring it to the desired ρ_b. Knitted nylon fabric, woven steel mesh, and scotch brite were placed at the bottom of the soil column to prevent soil loss.

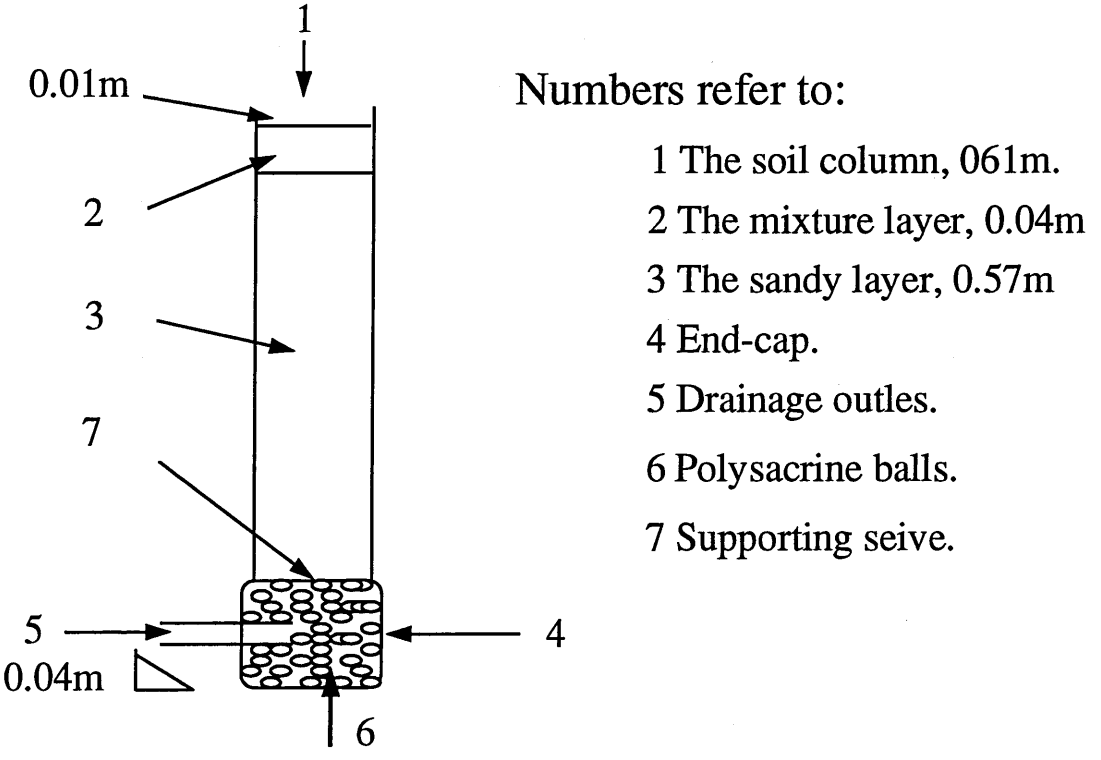


Figure 5.1. Schematic representation of the leaching column (not to scale).

The soil column was packed on a supporting sieve made of expanded metal with diamond shaped openings (19 X 40 mm). The supporting sieve was located in the middle of the end-cap (Figure 5.1). The bottom halves of the end-caps were filled with polysacrine balls, which were used for their light weight and large size to minimise the volume of effluent retained in them. A drainage outlet was placed in the bottom half of the end-cap, 0.04 m from its base. Joints in the column were sealed with a silastic gel to prevent any leakage. All columns were normally distributed on a table 0.27 m high to facilitate the collection of drainage water (Plate 5.1).

In the pot experiment, nine pots were used for each pot study (the FYM or the urea). They were prepared as follows:

Each pot of the FYM study was made of a corresponding weight of applied FYM (15.4 gm FYM) mixed with sand (400 gm) and sandy loam field soil (100 gm) with urea (0.13 gm) incorporated into the surface of the mixture. Each pot of the urea study was made of urea (0.13 gm) incorporated into the surface of the mixed sand with sandy loam field soil as above. In both studies, mixing was completed on a pot by pot basis. Woven steel mesh and scotch brite were used on the bottom of each pot to prevent the mixture loss.

The sand and sandy loam field soil were used in the study for specific purposes. The sand was used to mimic the dominant properties of the soils in the Kingdom of Saudi Arabia (KSA), whilst the sandy loam field soil was used for the purpose of inoculation. The sandy loam field soil was brought from the top 0.10-0.15 m of Silsoe College Farm.

As already indicated (Section 5, Chapter Two), the dominant properties of the soils in the KSA are light texture with low water holding capacity. Similar properties are seen from the analysis of the particle size distributions (Table 5.1) and total nitrogen (TN) and organic carbon (OC) content (Table 5.2) for both the sand and sandy loam soil used in this study. The particle size distribution was determined by the pipette method (BSI, 1990a). The TN content was determined using the Buchi equipment (Digestion Unit 435, Distillation Unit B316, and Scrubber Unit 412), whilst the Loss on Ignition (LOI) method was the method used to determine the OC values (BSI, 1990b).

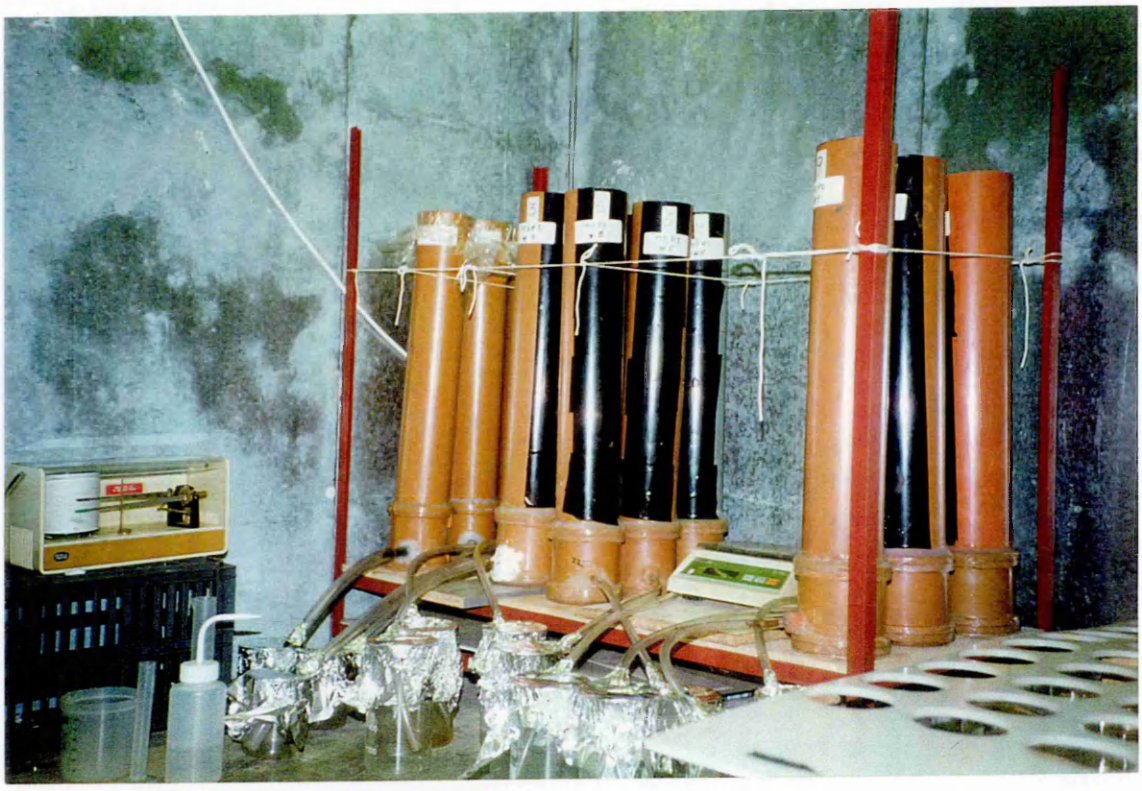


Plate 5.1. The distributions of the leaching columns.

Table 5.1 shows that the sand was dominated by sand fractions (94.32%) and thus resembles the light texture characteristic of the soils in the KSA. Also, the sandy loam field soil was dominated by sand fractions (74.49%). This suggests that the addition of the sandy loam field soil did not alter the desired light texture feature of the sand used in this study.

Table 5.1. Particle size distribution of the sand and sandy loam field soil used.

Soil	Particles size distributions (%)					
	Sand				Silt	Clay
	Coarse	Medium	Fine	Total		
Sand	16.29	62.49	15.54	94	2	4
Sandy loam field soil	10.32	42.69	21.49	74	13	13

Table 5.2. The total nitrogen (TN) and organic carbon (OC) for the FYM, urea, sand, sandy loam field soil used.

Properties	FYM	Urea	Sand	Sandy loam field soil
TN (%)	2.63	46	0.004	0.16
OC (%)	49.80	20	0.81	3.14

In addition the sand had a low organic matter content. The value of OC was 0.81%, approximately 1.40% of organic matter (Table 5.2). The low content of TN (0.004%) also confirms its low organic matter content.

The poor water holding capacity of the sand used in this study is seen in Figure 5.2, which illustrates the soil moisture characteristic curves of the FYM-sand mixture and the sand. The analysis was done by the sand table and pressure membrane technique (Smith & Thomasson, 1982).

Figure 5.2 shows that at all suctions the sand had a lower moisture content than the FYM-sand mixture. Available water (water held between field capacity and permanent wilting point, at 100 and 15000 cm respectively) for the FYM-sand mixture was 13% compared to the 8% for the sand. This shows firstly the poor water holding capacity of the sand used and secondly how FYM application improves it. The poor

WHC feature is generally observed for sandy soils (Rowell, 1994; Miller & Donahue, 1995).

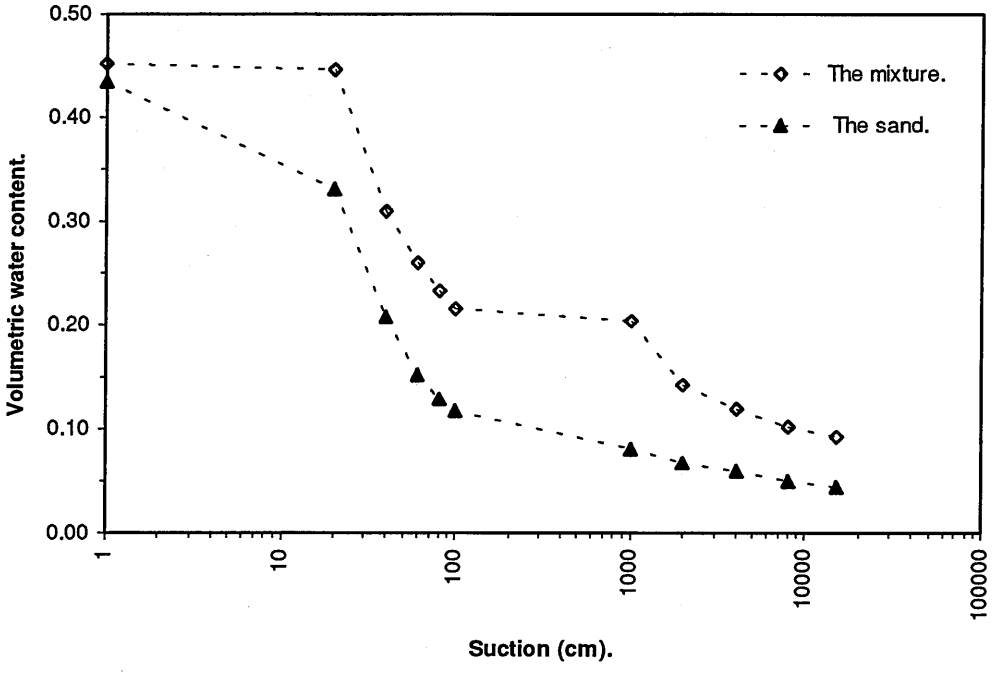


Figure 5.2. Soil moisture characteristic curves of the FYM-sand mixture and sand.

Thus the dominant properties of the soils in the KSA were simulated by the sand used in this study.

2.2- ARRANGEMENTS OF WETTING TREATMENTS:

In both the leaching column and pot experiments, water applications were undertaken at intervals of 4, 8, or 12 days resulting in different wetting treatments (Table 5.3).

In the leaching column experiment (C), wetting treatments were either intermittent between wet and dry conditions (A) or maintained continuously wet (C) (Table 5.3). The intermittent wet-dry conditions were obtained by allowing water to evaporate from the surface of the soil columns with water being applied at the designated wetting intervals. However, evaporation was prevented in the continuously wet treatment by covering the columns.

The purpose of the designated wetting treatments was to subject the applied FYM and urea in the mixture layers at the top of the soil columns to different soil moisture regimes. These regimes were intended to simulate the range of moisture contents found under a centre pivot irrigation system in a warm and dry climate. Thus, the conditions were planned to vary from a moisture content maintained at approximately field capacity (FC) at the height of the columns (CMC) to different conditions which were intermittent between wet and dry (CMA).

Table 5.3. The arrangements of wetting treatments for both experiments.

Wetting Intervals (days)	Leaching column experiments (C) Wetting plan		Pot experiments (P) Study	
	Intermittent (A)	Continuous (C)	FYM (F)	Urea (U)
4	CMA4	CMC4	PFM4	PUM4
8	CMA8	none	PFM8	PUM8
12	CMA12	none	PFM12	PUM12

Key examples: CMA4 is the leaching column experiment, intermittently wetted every 4 days. PUM4 is the pot experiment, urea study, moistened at 4 days interval. PFM4 is the pot experiment, FYM study, moistened at 4 days interval.

For the intermittent wet-dry treatments, water was applied every 4, 8, or 12 days for the CMA4, CMA8, or CMA12, respectively (Table 5.3). For the continuously wet treatment, water was applied every 4 days (CMC4).

In the pot experiment, however, the intermittent wet-dry plan was used for both FYM (PFM) and urea studies (PUM) (Table 5.3), since it was difficult to prevent water evaporation from the pots. For both studies, water was applied every 4, 8, or 12 day (Table 5.3).

Both the leaching column and the pot experiments were conducted in a controlled temperature room at 20°C. For both experiments, each wetting treatment was replicated three times. The replicates were distributed randomly.

2.3- THE C:N RATIO OF THE N SOURCES USED IN THE STUDY.

One of the major objectives of this study was to examine the release of mineral N under different wetting conditions. The release of mineral N from organic substances is controlled by their C:N ratio (See Section 3.2.1, Chapter One). It is thus necessary to examine the C:N ratio of the organic materials used in the study (i.e., the applied FYM and urea).

The C:N ratio of the applied FYM was 18.94. It was changed to 16.65 with the addition of urea (Table 5.2). Both values were within the range in which the release of N from the organic materials by microbial mineralisation takes place (e.g. Haynes, 1986a, Tisdale, ***et al.***, 1990; Troeh & Thompson, 1993). More details are given earlier (Section 3.2.1, Chapter One).

In conclusion the applied FYM and urea had a C:N ratio in which the release of mineral N is likely. Thus the variations in N mineralisation from the applied FYM are presumably due to the effects of the different soil moisture conditions provided by the designed wetting treatments on the microbial mineralisation of N from the applied FYM and urea.

3- MATERIALS AND EXPERIMENTAL PROCEDURES:

3.1- MATERIALS:

The materials used in the study were PVC pipes, pots, sand, sandy loam field soil, polysacrine balls (Grade H38), knitted nylon fabric, woven steel mesh, scotch brite, beakers, balance (Salter EK-12KA, Capacity 12 X 10^3 g ±1 g), fan, and distilled water.

3.2- EXPERIMENTAL PROCEDURES:

The objective of this section is to outline the procedure of both experiments conducted in the study.

3.2.1- Leaching column experiment:

This experiment was started on 14 January 1996. For each column, the packed sandy layer was moistened to field capacity (FC). The mixed layer was then placed on

top of the moist sand. Urea was incorporated into the surface of the mixture layer before it was also wetted to FC.

The packed sandy layer was moistened to FC by watering until drainage was observed. The column was then covered to impede evaporation, and excess water was allowed to drain freely. After drainage stopped the mixture layer was placed on top of the moist sandy layers. Urea was then incorporated into the surface of the mixture layers. Each mixture layer was then wetted to FC with water (71 ml). This was the water volume needed to bring the mixture layer to FC at the height of the soil column. This was determined using the sand table technique described by Smith & Thomasson (1982).

Volumes of water were applied to the columns of the CMA4, CMA8, and CMA12 treatments to make up the water lost through evaporation. 50% extra was added to represent an irrigation efficiency. The evaporated water from the columns was found by weighing the columns prior to water application and finding the difference from their weights at the FC moisture status. In this case, the weight of a column at FC is considered to be its weight after excess water, from prior water application, drains providing no evaporation loss has occurred. At least three days were needed for the excess water to drain out of the columns. Thus, in every wetting event for these treatments it was not feasible to obtain the weights of the columns at FC after water application without evaporation. Consequently, a reference weight strategy was used to determine the weight of the columns at the soil moisture of FC. The reference weight of a column was taken as the total weight of the materials used in the column (i.e., its components, the sand at FC, and the mixture layer and the water needed to bring it to FC).

Air movement above the columns was ensured by operating a fan throughout the experiment to enhance water evaporation from the surface of the columns. The fan was placed at a distance of 1.30 m from the nearest column that was located in the middle of the first row of columns. The height of the fan was the same height as the columns.

In the CMC4 treatment, water (90 ml) was applied constantly to each column in every wetting event. This was approximately the total average volume of water applied to the columns of the CMA4 treatment.

Throughout the experiment, excess water was allowed to drain freely from the bottom of the columns into beakers. The beakers were covered to prevent evaporation loss from effluent samples (Plate 5.1). The samples were then collected once a day, measured, and preserved with mercuric chloride ($HgCl_2$) 40 mg l^{-1}. The preservation was concluded with a final ratio of 1 ml of the solution added to a 100 ml of effluent (Rowland & Grimshaw, 1989). The preserved samples were then stored at 4°C prior to analysis for nitrate (NO_3^--N), ammonium (NH_4^+-N), total soluble nitrogen (TSN), total soluble salts (EC), and acidity (pH).

NO_3^--N and NH_4^+-N were analysed by a Technicon Auto-Analyzer II. Total soluble nitrogen (TSN) was found using the autoclave method (Williams, ***et. al.***, 1995). The EC and pH were determined using the Jenway 4070 and Camlab CG837 probes, respectively. The details of the analytical methods are summarised in Appendix A-1.

After the start of NO_3^--N breakthrough from the CMA4 treatment, a NO_3^--N check test was done for the CMA4, CMA8, and CMA12 treatments. This was done to observe the NO_3^--N distribution in the sandy layers of the soil columns for these treatments. The NO_3^--N check test was done by extracting NO_3^--N from soil samples taken from different depths of the soil columns. Soil samples were taken on the day before the next wetting event for each treatment. The samples were taken by a spatula from holes made on the sides of the columns. The NO_3^--N was extracted from the fresh soil samples by the 2*M* KCl method (Keeney & Nelson, 1982) and then analysed by a Technicon Auto-Analyzer II. Each soil sample removed from the columns was replaced with an equal mass of moistened sand to maintain the original arrangement.

The experiment ceased after the peaks of NO_3^--N breakthrough curves (BTC) were observed. The soil columns were then dismantled by excavating the soils from different sections from the top downwards. The sections had the following depths: top section (3 cm) of mixture layer for samples of the applied FYM, followed by a 2 cm section, then by five sections of 10 cm each, and finally the remaining 6 cm section.

The last six sections were from the sandy layer. The columns were dismantled after the last wetting event (October 4 1996) with time periods equal to wetting intervals for each treatment. Samples of the top two sections were immediately stored at 4°C to inhibit any microbial activity that may alter their N content. Samples from remaining sections were air dried. Soil moisture contents were determined gravimetrically for all soil samples from all sections (Rowell, 1994).

NO_3^--N was extracted from the fresh soil samples obtained from the sandy layers sections by the 2*M* KCl method (Keeney & Nelson, 1982) as before. The samples from the top two sections were analysed for total nitrogen (TN), using the Buchi equipment (Digestion Unit 435, Distillation Unit B316, and Scrubber Unit 412). These sections were also analysed for organic carbon (OC), as well as the air dried samples from other sections. The OC values were determined using the method of Loss on Ignition (LOI) (BSI, 1990b).

A breakthrough curve (BTC) for the chloride ion (Cl^-), a conserved ion, was obtained in order to assess the BTCs obtained for the NO_3^--N, a dynamic ion. The Cl^- test was done on one column that was constructed with sand only. The column was packed and moistened to FC before the test was started. Packing and wetting were completed as for those columns used in the N tests. The Cl^- test was done by applying 100 ml of chloride solution (600 mg Cl^- l^{-1}) to the surface of the moistened sand. After ten minutes, distilled water (200 ml) was applied. It was then followed by further water applications (200 ml) every five minute from the time water infiltrates into the sand. The total volume of water applied in this test was 2000 ml. The column was also allowed to drain freely. Effluent samples were then collected at five minute intervals. The volume of each sample was measured, and Cl^- was then determined in the samples using a Technicon Auto-Analyzer II.

3.2.2- Pot experiment:

In previous studies (Chapters 3 and 4) it was found that there was no oxidation of the NH_4^+-N ammonified from the applied FYM and urea. It was concluded that this was due to the lack of nitrifying bacteria in the soil-FYM mixture. Therefore, this experiment was carried out to examine the nitrification process in the applied FYM and

urea mixed with sand inoculated by a field soil under different wetting conditions (Experimental objective, Section 1.3.2).

As already mentioned (Section 1.3) the pot experiment consisted of two studies. The first was the FYM study in which nitrification was examined in soils with applied FYM and urea. The second was the urea study where the nitrification was examined in the soils with urea only. Both studies were inoculated with the sandy loam field soil as a source of nitrifying bacteria (Section 2.1).

Volumes of water applied to the pots were determined on the basis of their weight differences at FC (the weight of the pots immediately after drainage ceased without water evaporation loss) and their weights prior to water applications. 50% irrigation efficiency was also assumed in these studies. The weights of the pots at FC were determined in the first wetting event, by applying water (200 ml) to every pot. Then the pots were allowed to drain freely, and their weights at FC were immediately obtained. These weights were used throughout the experiment.

In all wetting events, excess water was allowed to drain freely from the bottom of the pots. Effluent samples were then collected, measured, and preserved with $HgCl_2$ as for those collected from the soil columns (Section 3.2.1).

In both studies, a bulked sample was made for every replicate. The bulking of each sample was made by accumulating 5 ml of the collected and preserved time series effluent samples. Bulked samples were then stored at 4^oC.

The time series and bulked samples of both studies were analysed for NO_3^--N and NH_4^+-N using a Technicon Auto-Analyzer II, and the TSN using the autoclave method (Williams, ***et al.***, 1995). The values of EC and pH were obtained in the time series samples only using Jenway 4070 and Camlab CG837 probes, respectively. At the end of the experiment, the TN was determined in the soil samples from both studies using the Buchi equipment (Digestion Unit 435, Distillation Unit B316, and Scrubber Unit 412). The details of the analytical methods used in the experiment are outlined in Appendix A-1.

4- RESULTS AND DISCUSSIONS:

The objective of this section is to discuss the results of both experiments conducted in the study.

4.1- RESULTS OF THE LEACHING COLUMN EXPERIMENT:

The aim of this experiment was to examine the effects of soil moisture conditions on the microbial release of N from the applied FYM with urea and hence its leaching losses from the soil columns simulating the soil profile (Section 1.3.1).

The experiment was designed to subject the applied FYM at the top of the soil columns to different moisture conditions (Section 2.1) that were obtained by different wetting treatments (Section 2.2). The moisture conditions in the top of the soil columns were planned to vary from the FC at the top of the soil columns to various drying conditions depending on the wetting intervals (Sections 2.1, 2.2, and 3.1).

Therefore, this section is organised to discuss the results of the leaching column experiment as follows:

1- The moisture variations in the soil columns.

2- The NO_3^--N check test.

3- N recovered in effluent.

4- N and OC residuals.

5- Total soluble salts (EC) and acidity (pH).

6- The chloride (Cl^-) test.

4.1.1- The moisture variations in the soil columns:

The aim of this section is to evaluate the wetting treatment plans adopted in the leaching column experiment. This evaluation is concluded in two ways:

A- Distribution of soil moisture with depth in the soil columns.

B- The proportion of the water applied which was yielded as effluent from each soil column.

4.1.1.A- Distribution of soil moisture with depth in the soil columns:

The soil columns were dismantled to different depths after the last wetting event at times corresponding to the wetting intervals for each wetting treatment (Section 3.2.1). This was done to determine the distribution of moisture as a function of depth in the soil columns prior to water application.

Figure 5.3 shows the variation of moisture distribution with depth for the CMA4, CMA8, CMA12, and CMC4 wetting treatments after dismantling the soil columns. In the sandy layer sections (from 5-15 cm to 55+ cm), moisture values were closely similar and constantly increased with depth for all wetting treatments. In contrast, the top two layers showed distinct differences in moisture values between the treatments.

The least significant differences ($LSD_{0.05}$) between the moisture values for the adopted treatments in every section depth are outlined in Table 5.4. The wetting treatments in the top three sections showed significant differences (P = 0.05) in moisture conditions. However, moisture differences were distinctly different in the top two sections (0-3 cm and 3-5 cm) than in the 5-15 cm section (Figure 5.3). Moisture conditions in other sections were not significantly different (Table 5.4). This suggests that the effects of soil moisture on N transformation in the sandy layers sections were closely similar. It also suggests that water evaporation losses were mainly from the top two sections (0-3 cm and 3-5 cm) containing the applied FYM.

In the top 0-3 cm and 3-5 cm sections, the moisture values for the CMC4 treatment were significantly higher than other treatments. They were 26.98%, a value approximately is equal to the FC value (25.89%) at the height of the soil columns (Figure 5.2), and 22.17% for the 0-3 cm and 3-5 cm sections (Figure 5.3), respectively. This demonstrates the effectiveness of covering the columns for the CMC4 treatment to obtain the desired moisture condition of FC at the top of the soil columns. This moisture condition is expected to be the most favourable for microbial activity and hence for N mineralisation (Miller & Johnson, 1964; Riechman, ***et al.***, 1966; Keeney, 1980).

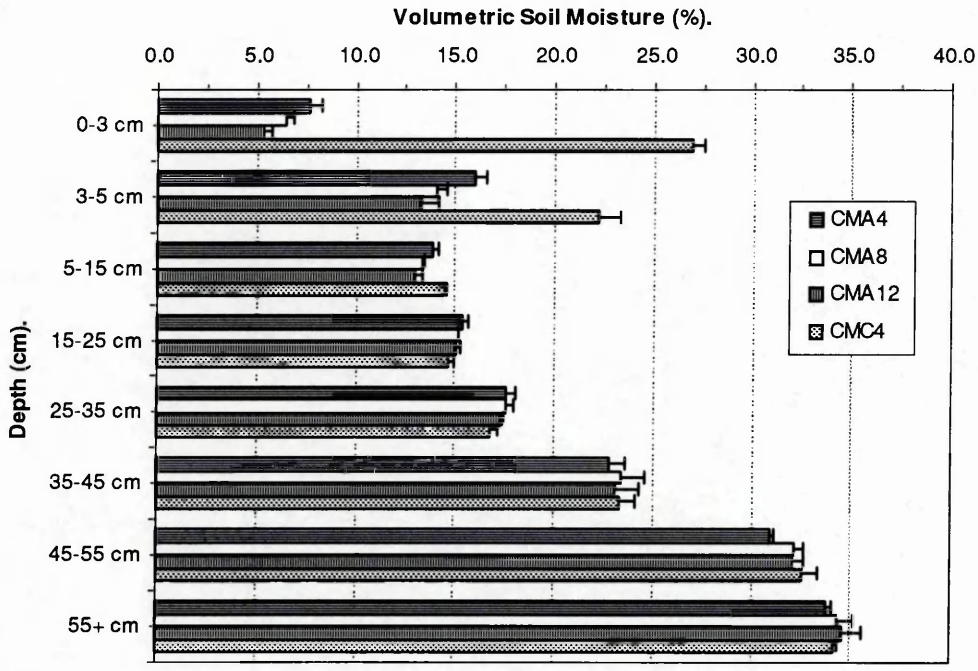


Figure 5.3. Variation of soil moisture distribution with depth after dismantling the soil columns for the treatments (Error bars refer to the standard error, SE).

Table 5.4. The moisture averages and LSD values in each section depth for the treatments adopted in the leaching column experiment.

Depth (cm)	treatment soil moisture averages (%, $cm^3\ cm^{-3}$)				$LSD_{(0.05)}$
	CMA4	CMA8	CMA12	CMC4	
0-3	7.59	6.47	5.36	26.98	1.60
3-5	16.02	14.10	13.24	22.17	2.70
5-15	13.91	13.41	12.94	14.44	0.78
15-25	15.42	15.21	15.09	14.67	NS
25-35	17.62	17.57	17.35	16.74	NS
35-45	22.83	23.40	23.07	23.36	NS
45-55	30.94	32.18	32.10	32.60	NS
55+	33.81	34.34	34.53	34.13	NS

N.B.: NS means not significantly different.

Figure 5.3 also shows that for the CMC4 treatment the decreasing trend in moisture values found in the top two sections (0-3 cm and 3-5 cm) continued in the following section (5-15 cm) followed by an increasing trend for other sections. Thus, the high moisture values in the top two sections for the CMC4 treatment were a result of the applied FYM.

As indicated earlier, the moisture value for the CMC4 treatment was significantly higher ($P = 0.05$) than the intermittently wetted treatments in the top 0-3 cm and 3-5 cm sections (Table 5.4). In these sections however differences in moisture for the treatments intermittently wetted were only significant between the CMA4 and CMA12. In the 0-3 cm section, the moisture values for the CMA4, CMA8, and CMA12 treatments were 7.59%, 6.47%, and 5.36%, respectively. Thus water evaporation losses, calculated from the presumed value at FC (26.89%) for the CMC4 treatment, were 72%, 76%, and 80% during the 4, 8, and 12 days wetting intervals designated for the CMA4, CMA8, and CMA12 treatments (Table 5.3), respectively. This suggests that for these treatments most of the evaporation losses from the soil columns occurred in the first four days of every wetting event.

Figure 5.3 also shows that the moisture values for the CMA4, CMA8, and CMA12 treatments exhibited an increasing trend between the 0-3 cm and 3-5 cm sections in contrast to the trend observed for the CMC4 treatment. However, the differences in moisture values at the 3-5 cm section between the CMC4 treatment and the treatments of CMA4, CMA8, and CMA12 were smaller than those found in the 0-3 cm section between them. This also suggests that evaporation losses from the soil columns were mainly from the top 0-3 cm section.

It was also observed from Figure 5.3 that, prior to water application, soil moisture in the top 0-3 cm section for the CMA4, CMA8, and CMA12 treatments decreased to values less than 9.16%, the moisture value of permanent wilting point at the suction 15000 cm (Figure 5.2). Mineral N however was detected in effluent collected from the columns of these treatments (as will be shown later). This suggests that micro-organisms responsible for N transformation in this section were capable of surviving such dry conditions. This agrees with the findings of other investigators who observed that micro-organisms are capable of tolerating low water potential (ψ_w) stress (Harris,

1980; Sommers, ***et al.***, 1980; Skujinš, 1981; Orchard & Cook, 1983; Sprent, 1987; Gomah, ***et al.***, 1990).

Sprent (1987) states that microflora are more capable of tolerating low water potentials (ψ_w) than higher plants and often survive long periods of desiccation. Orchard & Cook (1983) found that a log-linear relationship between soil water potential (ψ_w) and microbial activity held between -0.1 and -85 bar, as long as activity was not limited by substrate availability. Sommers, ***et al.*** (1980) indicated that actinomycetes and many fungi are capable of surviving very low water potentials (ψ_w) (-40 to -100 bars), but may be metabolically inactive.

The biophysical need of a micro-organism to reach a water potential equilibrium within its environment dominates the basic response of the organism to water potential (ψ_w) stress (Harris, 1980). Thus, the growth, survival, and activity response of a micro-organism to water potential stress is dictated by the effect of the stress on the physiological and substrate supply determinants of the rate and efficiency of growth and maintenance (Harris, 1980). Sommers, ***et al.*** (1980) implied that the activity of bacteria appears to be limited first by decreasing water potential (ψ_w), mainly because a decrease in the proportion of water filled pores reduces mobility of bacterial cells and limits substrate availability (i.e., lessening solute diffusion).

However, inactive micro-organisms during dry periods are capable of resuming their activity upon rehydration. Orchard & Cook (1983) mentioned that rewetting the soil caused a large and rapid increase in the respiration rate. Gomah, ***et al.*** (1990) found that drying cycles in either unamended or sewage sludge amended soils to -15 bar for a week decreased the activity of urease (26-56%) and amidase (22-32%), yet rewetting the soils to -0.33 bar resulted in an increase in both urease (16-147%) and amidase (15-98%) activity. It was also suggested that in dry areas cyanobacterial N_2-fixing flora are able to withstand years of desiccation, but their response to available moisture to resume metabolic activity requires less than one hour (Sprent, 1987; Skujinš, 1981). Dew may also be sufficient to reactivate the cyanobacteria during dry seasons (Skujinš, 1981).

It is therefore implied that microbial mineralisation of N from the applied FYM in the top section of the soil columns occurred despite the lower moisture content for the

CMA4, CMA8, and CMA12 treatments (Figure 5.3). Thus, the various moisture conditions at the top of the soil columns may have induced different effects on microbial mineralisation of N, resulting in different amounts of N being released from the applied FYM.

Thus, in conclusion, the designed wetting plan for the leaching column experiment (Section 2.2) induced significant differences in moisture conditions at the top sections of the soil columns containing the applied FYM. Evaporation losses from the intermittently wetted treatments (CMA4, CMA8, and CMA12) occurred mainly during the first 4 days of every wetting event from the top 0-3 cm section of the soil columns.

4.1.1.B- The proportion of effluent to water applied from each soil column:

In Section 4.1.1.A, it was shown that water evaporation loss from the soil columns of the CMC4 treatment was prevented. For the CMA4, CMA8, and CMA12 treatments evaporation loss occurred mainly during the first 4 days of each wetting event from the top 0-3 cm section of the soil columns. In this section, the relationship between water application and collected effluent in the soil columns of the wetting treatments is examined. Such a relationship gives the possibility of evaluating the wetting strategy used in the leaching column experiment (Section 3.2.1). Also it gives the possibility of assessing the leaching losses of N from the soil columns.

It has been suggested that the amount of NO_3^--N that leaches out from a soil depends on the amount of water that moves through the soil and the amount of NO_3^--N in the soil, when water drains through and out of the soil profile (Pratt, 1984; Knox & Moody, 1991). Pratt (1984) indicated that several studies have shown that the NO_3^--N leached from the irrigated land is well correlated with drainage volume and the applications of mineral N. Letey, ***et al.*** (1977) suggested that the amount of NO_3^--N contained in the tile effluent was well-correlated with total water discharge ($r = 0.89$ at $P = 0.01$) and the application of N fertiliser ($r = 0.73$ at $P = 0.01$).

Table 5.5 summarises the proportion of the water applied which yielded effluent from each soil column (Y/X). These proportional values were estimated from the linear regression of the cumulative water application (X) and cumulative collected

effluent (Y) for each soil column of the treatments (Appendix A-5.1). Also included are the degree of variations accounted for (r^2) of these relationships and the averages of the proportional values for the soil columns of each treatment.

Table 5.5. The proportional of effluent compared with water applied to the soil columns (Y/X) ($LSD_{0.05} = 0.16$).

Soil Columns	Treatments							
	CMA4		CMA8		CMA12		CMC4	
	Y/X	r^2	Y/X	r^2	Y/X	r^2	Y/X	r^2
No. 1	0.61	0.997	0.57	0.984	0.71	0.999	0.87	0.994
No. 2	0.63	0.996	0.53	0.973	0.58	0.996	0.94	0.998
No. 3	0.72	0.999	0.54	0.980	0.42	0.913	0.98	1.000
average	0.65		0.54		0.57		0.93	

Table 5.5 shows that the values of degree of variations accounted for (r^2) were high for all soil columns, always greater than 0.90. The strong relationships show that the columns are useful in evaluating the wetting strategy adopted in this experiment (Section 3.2.1) and for assessing the leaching loss of N from the soil columns.

Table 5.5 also shows that there were significant differences ($P = 0.05$) between the treatments in the quantities of effluent obtained in relation to the water applied to the soil columns (Y/X). However, from the $LSD_{0.05}$ value, it was only the CMC4 treatment that was significantly different to other treatments.

The high Y/X value for the CMC4 treatment shows that almost all water applied to the soil columns was collected in the effluent drained from them, as expected. Thus, it suggests that the covering method used for the soil columns of CMC4 treatment effectively retarded water evaporation from these columns. This confirms previous discussion (Section 4.1.1.A) which showed the effectiveness of covering the columns of the CMC4 treatment to retard evaporation, and hence to obtain the desired moisture condition of FC at the top of the soil columns.

The non-significant differences between the proportional values of the CMA4, CMA8, and CMA12 treatments shown in Table 5.5 resulted from the closely equable water evaporation losses from the soil columns (Section 4.1.1.A). The CMA4 treatment however had a Y/X value approximately 15-20% higher than the CMA8 and CMA12 treatments. This is possibly due to the fact that the soil columns for the CMA4 treatment were more frequently wetted than the columns for the CMA8 and CMA12. Such frequent wetting caused less evaporation loss from the CMA4 than the CMA8 or CMA12 treatments, as proportion of the total water volume applied. Thus, the insignificant differences between these treatments prove that most of the evaporation losses from the columns of the treatments occurred during the first 4 days of each wetting event. This agrees with the findings from the values of moisture shown in Figure 5.3 (Section 4.1.1.A).

It is known that the mass of N that leaches from a soil profile depends not only on the amount of water that percolates through it, but also on the amount of leachable N in the profile when water drains through and out of it (Letey, ***et al.***, 1977, Pratt, 1984, Abu Awad, ***et al.***, 1986, Scholefield, ***et al.***, 1993, Kamukondiwa & Bergström, 1994; Meek, ***et al.***, 1995). This suggests that the anticipated differences between the amount of N that leach from the soil columns will relate to the N concentration present in the soil columns, as well as to the volume of effluent that drains from the columns.

Differences in N concentrations in the soil columns, however, were due to the amounts of N that were mineralised by the micro-organisms from the applied FYM and urea. Thus, it is implied from the non-significant differences in the Y/X values between the CMA4, CMA8, and CMA12 treatments (Table 5.5), that differences in amount of N recovered from the soil columns of these treatments was determined by the microbial mineralisation of N at the top of the soil columns.

It is possible to conclude from Sections 4.1.1.A and 4.1.1.B that the designed wetting strategy adopted in the leaching column experiment (Section 2.2) was successfully achieved. The different intervals of water application (Table 5.3) resulted in significantly different moisture conditions at the top sections of the soil columns containing the applied FYM and urea. These conditions varied from the FC, the most favourable soil moisture condition for microbial activity, to various drying conditions

(Figure 5.3). Thus, the applied FYM was subjected to different moisture conditions, suggesting different microbial mineralisation of N from the applied FYM. The mineralised N is anticipated to leach from the soil columns in a different manner depending on differences in the relationship between the water application and collected effluent (Y/X) (Table 5.5).

4.1.2- The NO_3^--N check test.

A NO_3^--N check test was done for the CMA4, CMA8, and CMA12 treatments after the start of NO_3^--N breakthrough from the CMA4 treatment (Section 3.2.1). This test was made in order to observe the distribution of NO_3^--N with depth in the sandy layers of the soil columns of these treatments. The objective of this section is to assess the results of this NO_3^--N check test.

Figures 5.4, 5.5, and 5.6 show the distribution of extracted NO_3^--N (mg NO_3^--N kg^{-1}) with depth for the CMA4, CMA8, and CMA12 treatments, respectively. It is seen from these figures that the total and distribution of extracted NO_3^--N differed between these treatments. The differences in NO_3^--N concentrations between the treatments were attributed to differences in water application frequency (Table 5.3).

The extracted NO_3^--N concentrations increased in the soil columns in relations to the frequency with which they were wetted. The CMA4 treatment, the most frequently wetted, had the highest total NO_3^--N (Figure 5.4), whilst the lowest was found for the CMA12 treatment, the least frequently wetted (Figure 5.6).

As indicated earlier, the micro-organisms, which were capable of surviving the dry conditions experienced at the top of the soil columns prior to water application for these treatments (Figure 5.3), require only a short time to resume their activity after wetting (Section 4.1.1A). In addition, it was suggested that intermittent wetting and drying of the soil enhances microbial mineralization of N (Birch, 1964; Knight & Sküjins, 1981; Power, 1981; Bruin, ***et al.***, 1989; Pilbeam, ***et al.***, 1993; Tate, 1995).

Skujinš (1981) suggested that most arid-area plants and micro-organisms are dormant during dry seasons, but during the comparatively short wet intervals all biological activities, including N transformation processes, exhibit high rates. Bruin, ***et***

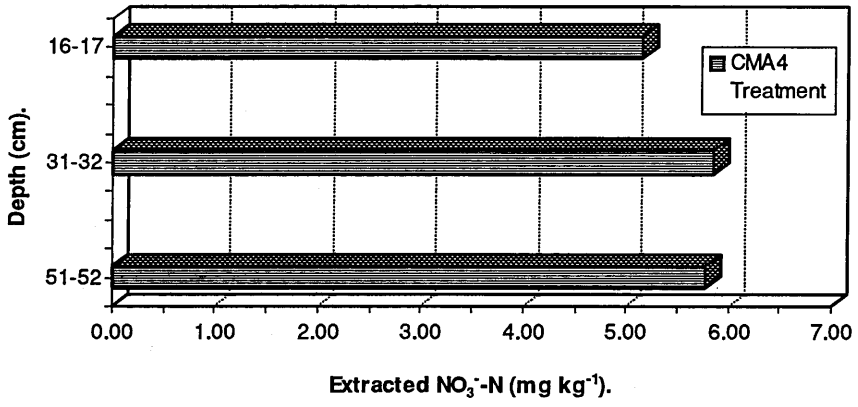


Figure 5.4. NO_3^--N distribution in the soil columns of the CMA4 treatment.

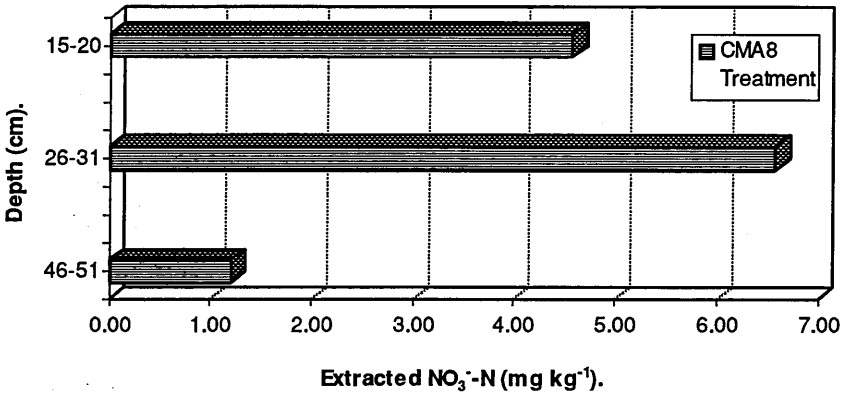


Figure 5.5. NO_3^--N distribution in the soil columns of the CMA8 treatment.

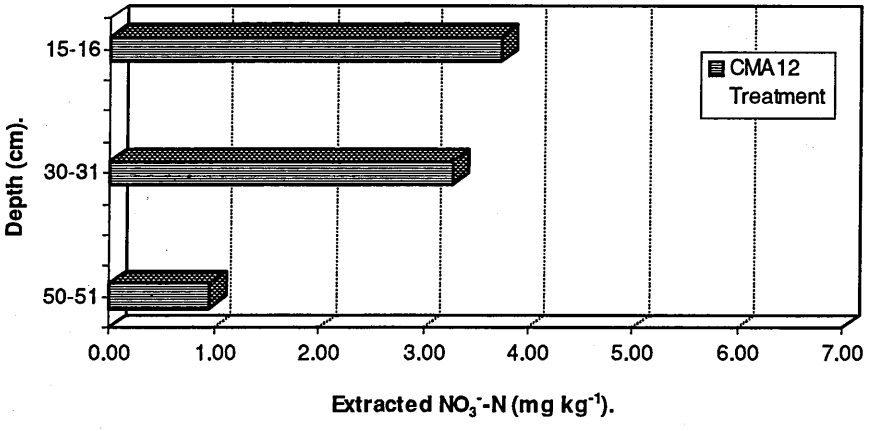


Figure 5.6. NO_3^--N distribution in the soil columns of the CMA12 treatment.

al. (1989) found that the rate of net mineralization at FC was 0.6 kg N ha^{-1} d^{-1} during the first 40 days which then decreased 10 times after 400 days, but the rate was twice as high on wet days under alternating wet-dry conditions. Bruin, ***et al.*** (1989) also indicated that the net nitrification rate during alternating wet-dry conditions was higher (1.96 kg N ha^{-1} d^{-1}) than at a constant FC (1.36 kg N ha^{-1} d^{-1}) until the NH_4^+-N was completely depleted.

The effects of wetting dry soil on gross mineralisation however are observed to be dependent on the soil matric potential prior to the change. Pilbeam, ***et al.*** (1993) reported that increasing the soil matric potential from -0.42 to -0.063 MPa or keeping the soil continuously at -0.41 MPa showed no effect on gross mineralisation rate, but a change from -5.91 MPa to either -0.42 MPa or -0.061 MPa increased rates of gross mineralisation to values greater than that of the soil continuously at -5.91 MPa, with the new rates less than those at constantly wet conditions.

The increase in mineral N as a result of wetting a dry soil is explained by the increase in the proportion of dead soil biomass upon soil drying. Thus, in response to the favourable moisture condition after rewetting, this dead biomass provides a source of readily mineralisable N and energy that can enhance microbial activity and hence mineral N production (Birch, 1960; Pilbeam, ***et al.***, 1993).

Also, Figures 5.4, 5.5, and 5.6 show that NO_3^--N had advanced further in the soil columns of the CMA4 treatment compared to the soil columns of CMA8 or CMA12 treatments. For the CMA4 treatment, the values of extracted NO_3^--N were 5.85 and 5.78 mg NO_3^--N kg^{-1} at the depths of 31-32 cm and 51-52 cm (Figure 5.4), respectively. For the CMA8 treatment the highest value of extracted NO_3^--N (6.58 mg kg^{-1}) was found at the middle depth (26-31 cm) of the soil columns (Figure 5.5). For the CMA12 treatment the NO_3^--N is seen to have advanced less than other treatments with the highest value (3.72 mg NO_3^--N kg^{-1}) at the top depth of 15-16 cm (Figure 5.6).

The different movements of NO_3^--N were also explained by differences in wetting frequencies between these treatments. Thus, it shows that NO_3^--N advanced in the soil

columns as a direct consequence of water application. This agrees with the findings of other investigators (Smika, ***et al.***, 1977; Abu Awad, ***et al.***, 1986; Meek, ***et al.***, 1995).

Abu Awad, ***et al.*** (1986) suggested that NO_3^--N leached down as the cumulative irrigation water increased. Abu Awad, ***et al.*** (1986) also indicated that an increase in NO_3^--N concentrations and movement occurred due to increasing cumulative total amounts of irrigation water that were applied and total amounts of urea fertilisers used. Meek, ***et al.*** (1995) found that each irrigation advanced the NO_3^--N peak approximately 20 cm, thus 14 to 15 irrigations resulted in a movement of the NO_3^--N peak to 280 to 300 cm. Smika, ***et al.*** (1977) suggested that NO_3^--N and water percolating to 150 cm depth were highly correlated (r = 0.95), with each cm of water carrying an average of 10.2 kg NO_3^--N ha^{-1}.

In conclusion, the results of this test demonstrate the role of water application in the microbial transformation of N from the applied FYM, as well as the NO_3^--N transport throughout the soil columns. They agree with the conclusion of the moisture variations in the soil columns (Section 4.1.1), which anticipated differences in amounts of mineralised N and leaching losses pattern. These differences were largely a result of the variations in the water applied-collected relationship caused by the wetting strategy adopted.

4.1.3- N recovered in effluent:

As indicated earlier (Section 3.2.1), the effluent samples collected from the soil columns of the treatments were analysed for NO_3^--N, NH_4^+-N, and TSN.

The objective of this section is to discuss the results of these analyses. The discussion is structured as follows:

A- NO_3^--N breakthrough curve (NO_3^--N BTC).

B- NH_4^+-N breakthrough curve (NH_4^+-N BTC).

C- Summary of N recovered.

4.1.3.A- NO_3^--N breakthrough curve (NO_3^--N BTC):

The averages of NO_3^--N concentrations (mg NO_3^--N l^{-1}) as a function of the cumulative effluent volume (ml) for the CMA4, CMA8, CMA12, and CMC4 treatments are shown in Figure 5.7.

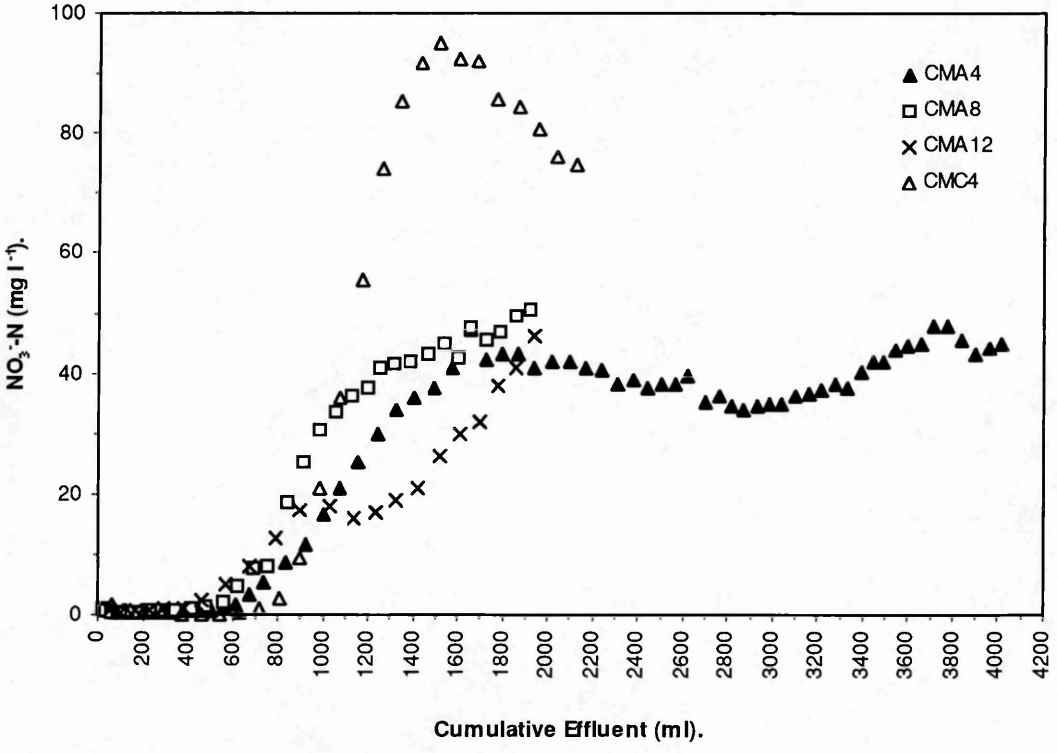


Figure 5.7. The NO_3^--N breakthrough curve (NO_3^--N BTC) for the wetting treatments.

Figure 5.7 shows that NO_3^--N concentrations for all the treatments exceeded the 11.3 mg NO_3^--N l^{-1} limit, a criterion for domestic water supplies (Train, 1979). This suggests that the use of FYM under the conditions of the experiment can result in potential contamination for ground waters.

Figure 5.7 also shows that the CMC4 treatment had the highest peak value (95.09 mg l^{-1}), which was significantly ($LSD_{0.05}$ = 19.70) higher than values for the CMA4, CMA8, and CMA12 treatments (47.83, 50.46, and 46.23 mg l^{-1}, respectively). This is due to the differences in moisture conditions at the top sections of the soil columns containing the applied FYM (Figure 5.3, Section 4.1.1.A).

It was indicated in Section 4.1.1.A that the moisture condition for the CMC4 treatment was maintained at the FC, whilst other treatments led to intermittent wet and dry conditions. The FC condition was observed to be the optimum for N mineralisation and nitrification (Sabey, 1969; Agarwal, ***et al.***, 1971a; Adriano, ***et al.***, 1974; Stanford & Epstein, 1974; Haynes, 1986b; Plymale, ***et al.***, 1987; Tisdale, ***et al.***, 1990).

Plymale, ***et al.*** (1987) suggested that the proportion of mineralised N converted to NO_3^--N was significantly related ($P < 0.01$) to soil moisture. Haynes (1986b) & Tisdale, ***et al.*** (1990) also suggested that in general the maximum rate of nitrification occured at soil moisture potentials in the range of -0.1 and -0.33 bar, which encompassed the moisture condition of FC.

Sabey (1969) found that the maximum rate of NO_3^--N accumulation occurred at 0.1 bar tension. Sabey (1969) also suggested that the relative rates of NO_3^--N accumulation at 0.1, 0.3, 1, 5, and 15 bars tension were 1.0, 0.71, 0.53, 0.29, and 0.13, respectively. This is explained by the sensitivity of the nitrifying micro-organisms to the dry condition.

Tate (1995) suggested that NH_4^+-N tends to accumulate in dry soils because the ammonifying micro-organisms are less sensitive to the low-water activities than are the nitrifiers.

However, enhanced nitrification occurs on moistening a dry soil (Birch, 1960; Bruin, ***et al.***, 1989; Pilbeam, ***et al.***, 1993). Sprent (1987) mentioned that following dry periods in arid areas each rain shower rehydrates sufficient numbers of micro-organisms to allow some mineralisation and nitrification. Wild (1988) also suggested that in hot regions having a pronounced dry and wet season, NO_3^--N is produced most rapidly at the start of rainfall and only slowly during the rainy season itself.

Pilbeam, ***et al.*** (1993) observed that under constant moisture conditions (-0.015, -0.063, -0.42, and -5.91 MPa) the highest percentage of NO_3^- recovered was at -0.063 MPa, an approximate condition of FC, decreased to the least at -5.91 MPa. The percentage of recovered NO_3^-, however, increased after moistening the soil from the -

5.91 to either -0.42 or -0.063 MPa, with the new percentages less than that under the constantly wetted condition at -0.063 MPa.

As indicated earlier (Section 4.1.1.B), the amount of NO_3^--N that leaches from the soil columns depends on the volume of effluent that drains out of the columns and the amount of NO_3^--N in the columns. The amount of NO_3^--N in the columns is related to the amount of N mineralised from the applied FYM at the top of the soil columns.

Thus, a statistical analysis was carried out to quantify the differences in N mineralisation at the top of the soil columns. It was done for the NO_3^--N concentration of the treatments recovered at a specific cumulative effluent volume (1500 ml ±50) from each column. This volume was chosen in relation to the peak value of the CMC4 treatment (Figure 5.7). The values of NO_3^--N concentration used for the test and the $LSD_{0.05}$ are summarised in Table 5.6.

Table 5.6. The summary of the NO_3^--N concentrations of the treatments.

Soil Columns	Treatments			
	CMA4	CMA8	CMA12	CMC4
No. 1	35.67	34.29	34.47	97.35
No. 2	50.01	53.72	44.22	86.88
No. 3	43.77	50.84	52.89	111.15
Average	43.15	46.28	43.86	98.46
$LSD_{0.05}$	18.70			

Table 5.6 shows that only the CMC4 treatment that was significantly (P = 0.05) different from other treatments. This agrees with the significant differences observed for the peak values of the treatments (Figure 5.7). It also agrees with the significant differences in the moisture conditions at the top of the soil columns (Table 5.4).

For the CMA4, CMA8, and CMA12 treatments, the differences in NO_3^--N concentrations were non-significant. This is explained by their close moisture conditions at the top of the soil columns before water application (Figure 5.3, Section 4.1.1.A).

This suggests that differences in moisture conditions for the applied FYM affected the microbial N mineralisation (ammonification and nitrification). At the most favourable condition of FC, mineralisation was at the highest relative rate, which then decreased under the dry, less favourable, conditions causing a decrease in N transformation.

4.1.3.B- NH_4^+-N breakthrough curve (NH_4^+-N BTC).

Figure 5.8 illustrates the average of NH_4^+-N concentrations (mg NH_4^+-N l^{-1}) as a function of the cumulative effluent volume (ml). The figure outlines the NH_4^+-N BTC for the CMA4, CMA8, CMA12, and CMC4 treatments.

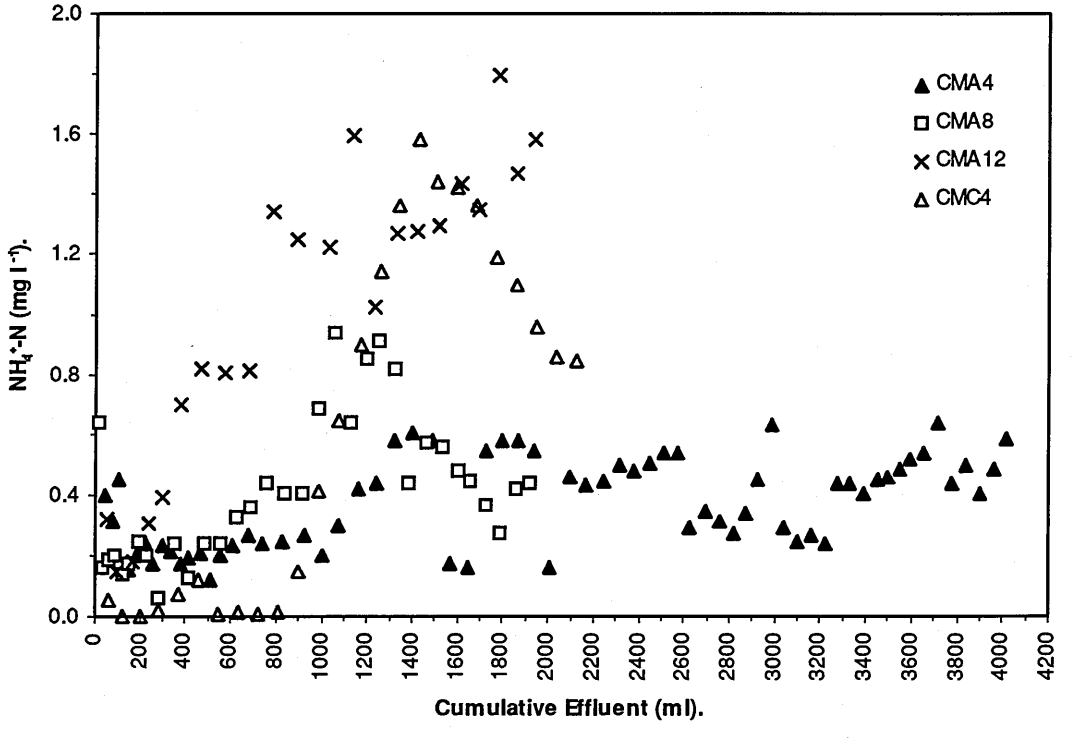


Figure 5.8. The NH_4^+-N breakthrough curve (NH_4^+-N BTC) for the wetting treatments.

Figure 5.8 shows that the values of NH_4^+-N concentration leached from the soil columns were small, generally less than 2 mg l^{-1}. This agrees with the observations of other investigators who found NO_3^--N is the primary form of N in effluent draining from a soil profile (Dowding, 1981; Macduff & White, 1984; Haigh & White, 1986; Wild, 1988).

Macduff & White (1984) suggested that the concentration of NH_4^+-N in the catchment drainage was negligible compared with that of NO_3^--N. Burt & Arkell (1987) also suggested that major NO_3^--N losses occurred in winter when there was no soil moisture deficit, with 80% of N losses from the annual applied fertiliser in the form of NO_3^--N.

Williams (1975) also reported in a study examining the chemical composition of drainage water from Saxmundham and Woburn in a period between 1970 and 1975 that NH_4^+-N concentrations were much smaller than the NO_3^--N concentrations. During the period, the mass of NH_4^+-N lost from all the land drained at Woburn was 7 kg compared with the 1556 kg of the mass of NO_3^--N lost.

The small NH_4^+-N concentrations in this experiment contrast the NH_4^+-N findings observed in previous pot studies (Chapters 3 and 4), where the concentrations of NH_4^+-N leached were larger than the NO_3^--N. This indicates that the NH_4^+-N ammonified from the applied FYM was first nitrified and then leached as NO_3^--N.

4.1.3.C- Summary of N recovered.

The average masses of different forms of N (NO_3^--N, NH_4^+-N, and TSN) recovered in effluent are summarised in Table 5.7. The percentages and rates of losses of N are also included in the table. The percentages were calculated in reference to the total N applied from the FYM and urea.

Table 5.7. The summary of different N forms recovered in effluent.

Treatments		CMA4	CMA8	CMA12	CMC4
No. of wetting events		66	33	22	25
TSN	mg	129.82	49.29	41.66	97.35
NO_3^--N		119.50 (25.70)	47.10 (10.13)	38.50 (8.28)	92.22 (19.83)
NH_4^+-N		1.45 (0.31)	0.82 (0.18)	2.01 (0.43)	1.37 (0.29)
Sum of NO_3^--N & NH_4^+-N		120.95	47.92	40.51	93.59
Rate of loss	mg day^{-1}	0.46	0.18	0.15	0.94

N. B.: values between parentheses are % of lost N from the total applied N.

Table 5.7 shows that the TSN values (mg) were approximately equal to the total mineral N (NO_3^--N and NH_4^+-N). Also seen from the table that the masses of NH_4^+-N leached were negligible compared to the NO_3^--N, as observed previously (Section 4.1.3.B). This demonstrates that the released NH_4^+-N, solubilized or ammonified, from the applied FYM was transformed to NO_3^--N before being leached out.

Table 5.7 also shows that the N losses from the CMC4 treatment were greater than from other treatments. For the CMC4 treatment, the rate of losses was twice as high the rate for the CMA4 treatment, which was nearly 3 times greater than those for the CMA8 and CMA12 treatments. This is explained by the observed differences in the Y/X relationships between the treatments (Table 5.5).

As discussed earlier (Section 4.1.1.B), the rate of loss is related to differences in the amount of N mineralised between the treatments. It also substantiates the role of a leaching strategy in determining the load of N leaching losses from the soil profile.

It is thus concluded from Sections 4.1.3 (A, B, and C) that the wetting strategy designed to simulate irrigation practices caused significant differences (P = 0.05) in amount of N mineralised between the treatments. The maximum amount was under the condition of FC, which then decreased as the drying condition increased.

The relation between the amount of N mineralised and moisture conditions is explained by the effects of moisture on microbial activity, as expected. Ammonifying micro-organisms were less sensitive to dry conditions than the nitrifiers. However, both ammonification and nitrification were enhanced on changing a dry condition to a moist.

The leaching losses of N were mainly in the form of NO_3^--N. For all the treatments, the NO_3^--N concentrations exceeded the acceptable limits for domestic water supplies, suggesting a contamination potential to ground waters. The rates of N losses were dependent on the amount of N released as well as the effluent-water application relationship.

4.1.4- N and OC residuals:

As already indicated (Section 3.2.1), after dismantling the soil columns, NO_3^--N was extracted from soil samples obtained from the sandy layer sections. The top two sections of the soil columns were analysed for total nitrogen (TN). Also, organic carbon (OC) was determined in all the sections of the soil columns. The purpose of these analyses was to examine the change in the TN content of the applied FYM and to assess the residuals of N and OC in the soil columns.

This section is aimed to discuss the results of these analyses with the following focus:

A- The N residuals in the soil columns.

B- The OC residuals in the soil columns.

4.1.4.A- The N residuals in the soil columns:

The N residuals in the soil columns consisted of the TN values (mg N kg^{-1}) in the top two sections and the values of extracted NO_3^--N (mg NO_3^--N kg^{-1}) from the sandy layers' sections. The extracted NO_3^--N values were assumed to be equal to the TN in the sandy layers' sections. The assumption was based on the following:

i- These sections consisted of sand only, that originally had low TN content (Table 5.2, Section 2.1).

ii- Sand fractions are known for their poor NH_4^+-N fixation (Young & Aldag, 1982) and adsorption or retention (Nommik & Vahtras, 1982; Cameron & Haynes, 1986).

iii- N results (Sections 4.1.3. A, B & C) showed that NO_3^--N was the main form of N in effluent, suggesting that NO_3^--N was the primary N form in the soil solution of these sections.

Also, the analysis for low TN content is impractical to yield satisfactorily precise and consistent results. This is seen from Appendix A-5.2 and shows large discrepancies between replicated analyses, which were done for soil samples randomly selected from different depths of the soil columns of the treatments. For each soil sample, the coefficient of variations (C.V.%) showed the poor agreement between the

TN values. This suggests that the results were not adequately reliable to examine differences between the treatments in the TN values for these sections. Thus, extracted NO_3^--N values were used instead.

The results of the N residuals for the CMA4, CMA8, CMA12, and CMC4 treatments are summarised in Figure 5.9. The figure shows that in the top 0-3 cm section the TN values were not significantly different (P = 0.05) between the treatments. Though the values had a decreasing trend in the following order CMA12 > CMA8 > CMA4 > CMC4 (100.04, 92.68, 87.49, and 82.11 mg N kg^{-1}, respectively). The trend was in the opposite order for the rates of N losses (Table 5.7). This corroborates the relationship between N mineralisation and rate of losses, as expected.

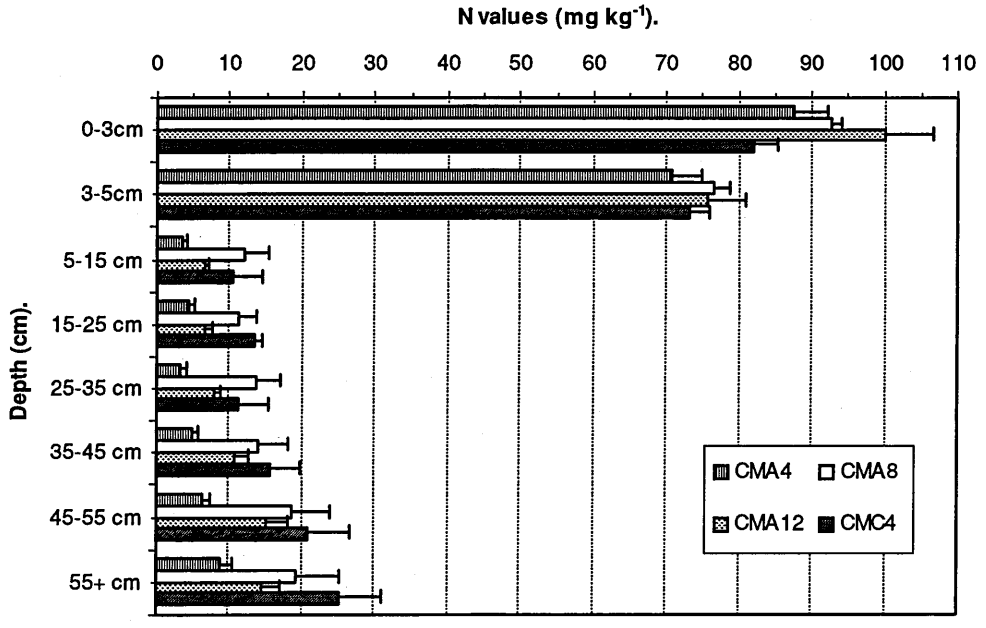


Figure 5.9. The N residuals in the soil columns with depth for the treatments (error bars refer to the standard errors).

In the 3-5 cm section, the TN decreased to smaller values than those in the top 0-3 cm section. The values were 75.80, 76.58, 70.83, and 73.11 mg N kg^{-1} for the CMA12, CMA8, CMA4, and CMC4 treatments, respectively. Thus, these close values and the non-significant differences between the TN values at the top section imply that the easily decomposable fractions in the applied FYM were mineralised in all the treatments.

This is supported by the results of experiments 1 and 2 (Chapters 3 and 4, respectively). The results showed that most of mobile N was released from the applied FYM in the first few wetting events. Also, Saviozzi, ***et al.*** (1995) indicated that the measured components (total mass, organic and soluble carbon, and water soluble sugar) of crop residues (rape, sunflower, and soybean) decreased most rapidly during the first month of incubation in bags buried in soil, suggesting that the decomposability of residues did not differ largely after the easily degraded fractions were lost.

In the sandy layers sections, the residual N values were smaller than the values at the top two sections (Figure 5.9). The values showed that considerable amounts of NO_3^--N were still in the soil columns. The values also showed an increasing trend with depth, which suggests that NO_3^--N concentration in the immediate effluent leaching from the soil columns is declining.

The increasing trend for the residual N in the sandy layers sections also demonstrates the effects of water application practices on the NO_3^--N movement in the soil columns. This is shown by the small values of N residual for the CMA4 treatment and the relatively high NO_3^--N values at the bottom of the soil columns for the CMA8 and CMA12 treatments, which contradict the findings of the NO_3^--N check test (Figures 5.4, 5.5, and 5.6, Section 4.1.2). In the check test, it was found that the CMA4 treatment had higher extracted NO_3^--N values than the CMA8 and CMA12 treatments, and the NO_3^--N had advanced less in the soil columns for the CMA8 and CMA12 treatments.

This implies that N leaching losses are influenced by the leaching management. Trudgill, ***et al.*** (1991) indicated that losses of NO_3^--N from the Slapton catchment, UK appeared to be transport limited and independent of variations in soil NO_3^--N supply, suggesting that leaching losses of NO_3^--N relate to the generation of soil through flow water than to land use alone. Devitt, ***et al.*** (1976) suggested that higher mass amounts of NO_3^--N were lost under irrigation management where a high leaching volume was used. Ritter (1989) in a review of NO_3^--N leaching under irrigation in the USA concluded that the mass of NO_3^--N leached is directly related to the leachate volume.

4.1.4.B- The OC residuals in the soil columns.

As already indicated, all the sections of the soil columns were analysed for OC. The analysis was done to assess N mineralisation due to the direct association between the processes of both N and C mineralisation (Tate, 1995).

Figure 5.10 outlines the values of OC (mg OC kg^{-1}) with depth (cm) for the CMA4, CMA8, CMA12, and CMC4 treatments. The figure shows that the values in the top 0-3 cm section were 149.22, 142.34, 153.83, and 150.75 mg kg^{-1}, respectively. They decreased to 80.90, 82.41, 91.41, and 120.13 mg kg^{-1} in the 3-5 cm section, respectively. The OC values also continued to decrease in the sandy layers sections.

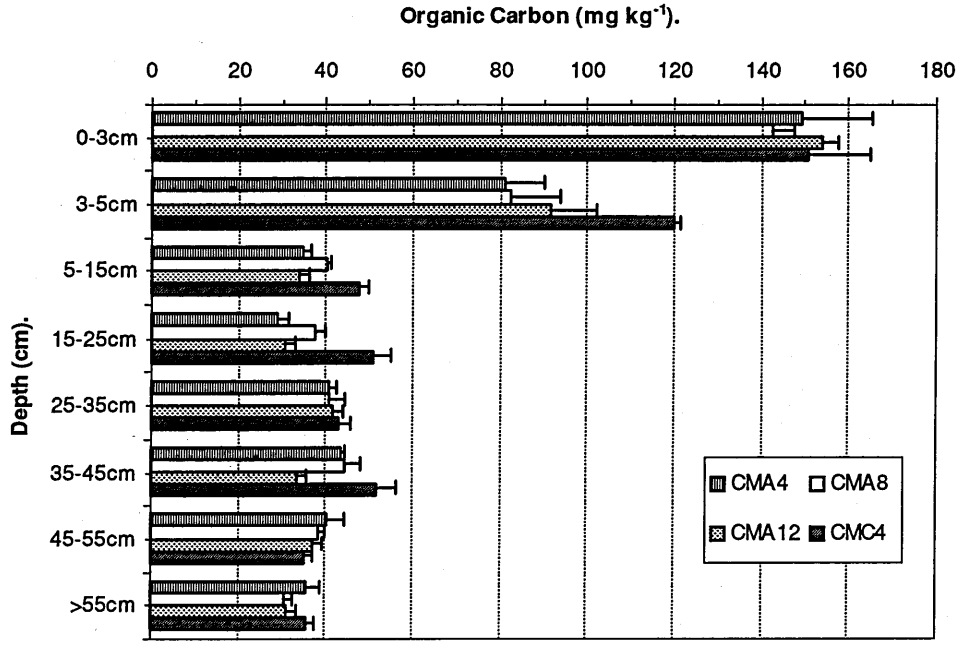


Figure 5.10. The OC residuals in the soil columns with depth for the treatments (error bars refer to standard errors).

The coupled decrease in both N and OC seen here was also observed by other investigators. Johnston & Poulton (1976) indicated in a report studying the effects of cropping and manuring from 1852 to 1975 on the exhaustion land and changes in the nitrogen, phosphorus, and potassium (NPK) content of soils on the FYM treated soils, both N% and C% declined after the FYM additions ceased in 1901. Johnston (1991) suggested that applications of 37.5 and 75 t FYM ha^{-1} yr^{-1} from 1942 to 1976 to the

sandy loam at Woburn increased the OC from 0.87 to 1.64 and 2.26%, respectively. However, once the additions of FYM stopped the soil organic matter content began to decline rapidly. Also, C mineralisation was found to be stimulated by the addition of N (Green, ***et al.***, 1995) and by repeated wetting and drying cycles (Agarwal, ***et al.***, 1971a).

Thus the decline in the values of TN and OC validate the assumption of the process of the N transformation throughout the soil columns. Tate (1995) stated that a basic principle of biochemistry is that all oxidations must be balanced by reductions, i.e., electrons generated in the oxidations processes are balanced by an electron acceptor. Tate (1995) also suggested that soil microbes, as all living entities, derive the energy necessary for cellular function through oxidation reactions, which require terminal electron acceptors. Among these acceptors are Oxygen (O_2), nitrate (NO_3^-), nitrite (NO_2^-), and a variety of organic compounds, such as acetate and pyruvate (Tate, 1995). This implies that the oxidation of OC compounds is coupled by the transformation of N serving as an electron acceptor.

In conclusion, the results of TN and OC residuals in soil columns showed that N transformation processes occurred throughout the soil columns, as expected. The concentrations of NO_3^--N in the sandy layers sections indicated that considerable amounts of NO_3^--N were still in the soil columns susceptible to leaching losses. These concentrations however were expected to decrease in the late effluent leaching from the soil columns, as seen from their increasing trend with depth.

4.1.5- Total soluble salts (EC) and acidity (pH):

As indicated earlier (Section 3.1.2), both EC and pH were determined in the effluent samples collected from the soil columns. They were determined because N transformation was found to be affected by the EC (Singh, ***et al.***, 1969; Hendrickson, ***et al.***, 1978; McCormic & Wolf, 1980; Groffman, ***et al.***, 1995) and pH (Smith, 1964; Keeney, 1980; Adams & Martin, 1984).

The objective of this section is to examine the results of EC and pH in effluent with regard to the N results. The following aspects are discussed in this section:

A- The EC results. B- The pH results.

4.1.5.A- The EC results.

Figure 5.11 shows the EC values (dS m^{-1}) in the cumulative effluent (ml) for the CMA4, CMA8, CMA12, and CMC4 treatments. The figure shows that the EC had a trend similar to the NO_3^--N BTC (Figure 5.7). The similarity between these trends was due to the effects of NO_3^--N concentrations in the effluent.

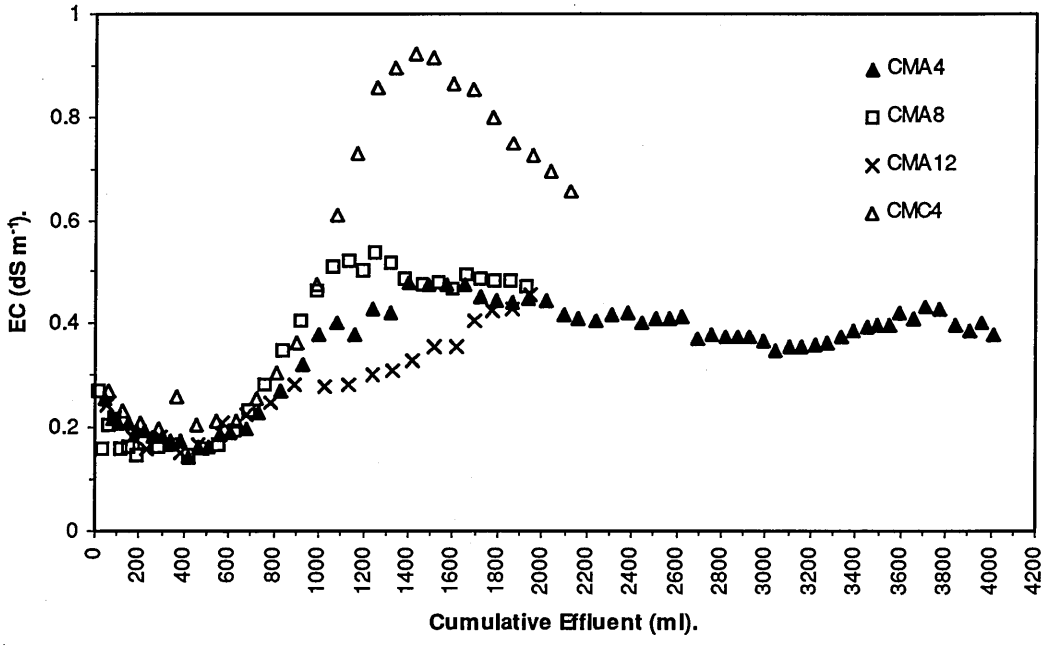


Figure 5.11. The EC values in effluent collected from the soil columns of the treatments.

Figure 5.11 also shows that the EC of the effluent is generally low, less than 1 dS m^{-1}. These values are expected not to cause adverse effects on microbial N transformations (Singh, ***et al.,*** 1969; Hendrickson, ***et al.***, 1978; McCormic & Wolf, 1980; Groffman, ***et al.***, 1995). Microbial activity was found to be suppressed by higher salt concentrations than these values (Chapter 4, Discussion of EC results).

4.1.5.B- The pH results.

The pH values in the cumulative effluent (ml) for the CMA4, CMA8, CMA12, and CMC4 treatments are shown in Figure 5.12. The values were generally within a close range, varying from 6.5 to slightly less than 8.0. This range is favourable one for microbial activity (Smith, 1964; Keeney, 1980; Adams & Martin, 1984).

Focht & Verstrate (1977) suggested that the growth and metabolism of the autotrophic nitrifying bacteria (the nitrifiers in agricultural soils) are optimal in the neutral to slightly alkaline range (pH 7-8). The pH range for complete nitrification is restricted due largely to toxicity of free ammonia (NH_3) at an alkaline pH and nitrous acid at an acidic pH to Nitrobacter (at pK_a values of 9.3 for NH_3/NH_4^+ and 4.2 for HNO_2/NO_2^-, respectively). This suggests that nitrification was not restricted by pH.

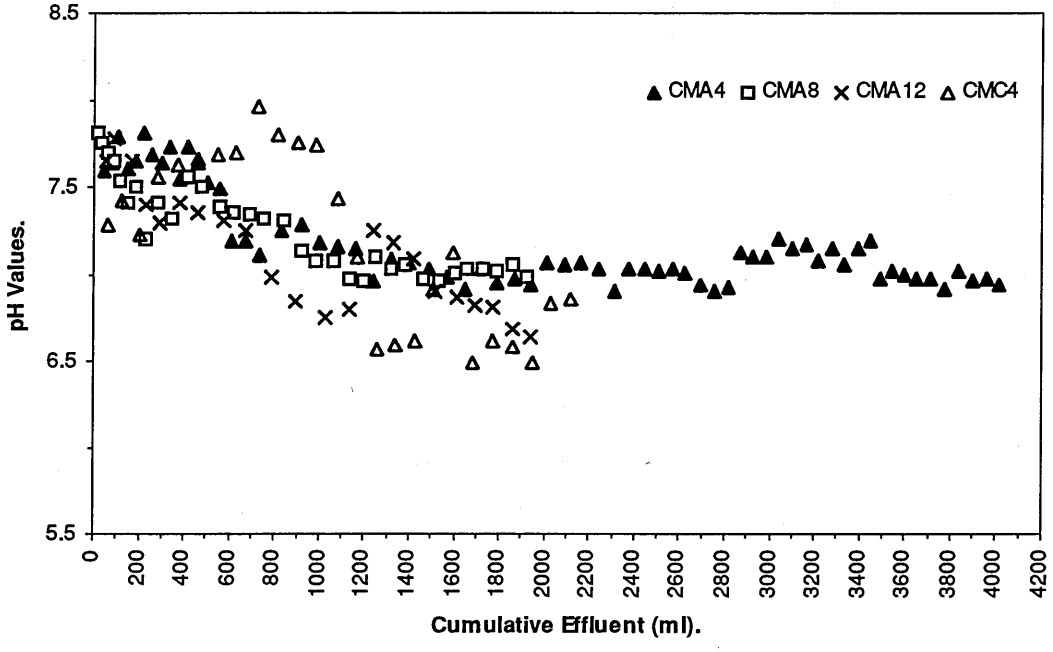


Figure 5.12. The pH values in effluent collected from the soil columns of the treatments.

Thus, it is concluded from Sections 4.1.5 (A & B) that in all the treatments N mineralisation was not suppressed by the EC nor by pH, as seen from their values in effluent collected from the soil columns. The pH values were also in the optimum range for nitrification, which resulted in the dominance of NO_3^--N in effluent.

4.1.6- The chloride (Cl^-) test:

The flow of chloride ions (Cl^-) is commonly used in solute transport studies. It is preferred because it is a simple anion and assumed to be a non-reactive. Thus, as already indicated in Section 3.2.1, a breakthrough curve for the chloride ion (Cl^- BTC) was obtained using one column packed with sand only. The Cl^- test was used to compare with the NO_3^--N BTCs (Figure 5.7, Section 4.1.3.A).

The aim of this section is to discuss the results of the Cl^- BTC and to compare it with the NO_3^--N BTC.

Figure 5.13 shows the Cl^- concentration (mg Cl^- l^{-1}) in the cumulative effluent (ml) collected from the column used for the Cl^- test. The figure shows that the pattern of Cl^- BTC is similar to the pattern of NO_3^--N BTC for the CMC4 treatment (Figure 5.7). This agrees with the suggestions of other investigators who observed that a Cl^- leaching from a soil profile showed a similar pattern to the NO_3^--N leaching (Garwood & Tyson, 1973; Langdale, ***et al.***, 1979; Cameron & Wild, 1982).

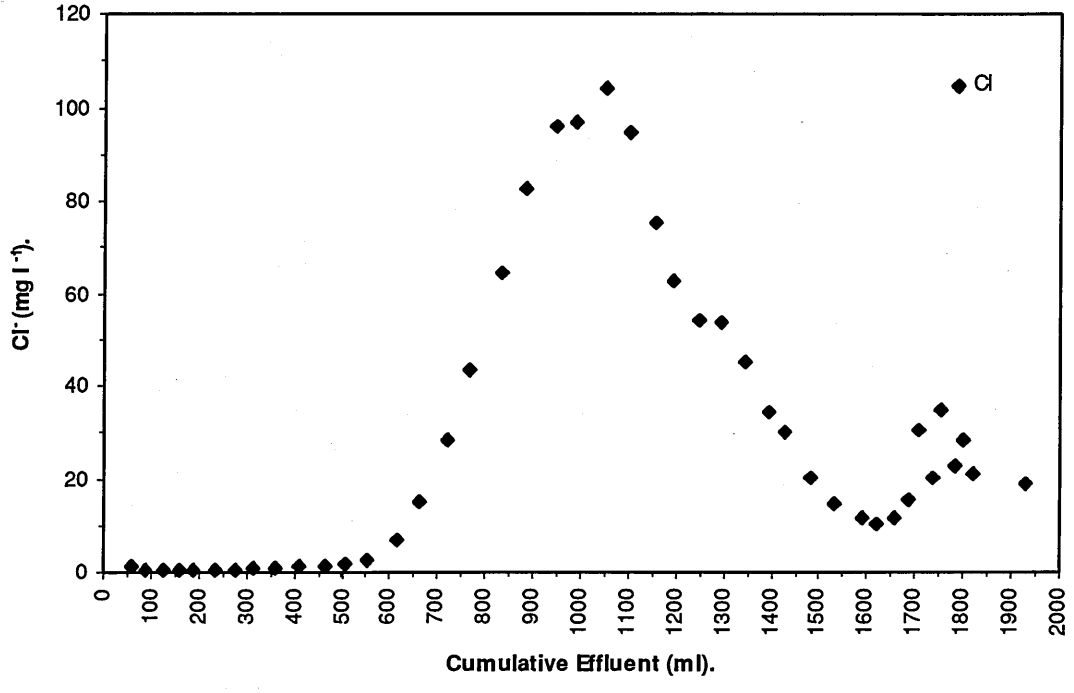


Figure 5.13. The chloride breakthrough curve (Cl^--BTC).

For the CMA4, CMA8, and CMA12 treatments, the leaching pattern of the NO_3^--N BTC was, however, different from the Cl^- BTC. These treatments had a plateau form of NO_3^--N BTC (Figure 5.7). This is attributable to the drying process that was allowed during the wetting events for these treatments. The drying process is likely to have induced a capillary movement of water, which caused an upward movement of NO_3^--N with the upward moving water (Tisdale, ***et al.***, 1990). Thus the upward movement of NO_3^--N slowed the downward movement, which then produced the plateau form of NO_3^--N BTC. This suggests that, besides the effects of drying on N

mineralisation, the drying process influences the leaching pattern of NO_3^--N determining the configuration of the BTC.

The effects of the drying process on the pattern of the NO_3^--N BTC are also ascertained from differences in the start of the NO_3^--N BTC between the treatments (Figure 5.7). The start of the NO_3^--N BTC in the effluent occurred in the order CMC4 > CMA4 > CMA8 > CMA12 (812.33, 610.33, 464.33, and 380.67 ml cumulative effluent, respectively). This shows, as expected, that the drier the treatment, the less volume of effluent required to start the BTC. Such findings were also observed by Nielsen & Biggar (1961), who suggested that desaturating the soil progressively shifts the BTCs to the left at the initial breakthrough. Nielsen & Biggar (1961) also indicated that the shift is perhaps due to the incomplete displacement of one fluid by another.

For the Cl^- BTC, the start occurred at 551.00 ml cumulative effluent (Figure 5.13). This shows that Cl^- started breaking through with less effluent than the CMA4 and CMC4 treatments. This is explained by the differences between the forms in which both the N and Cl^- were applied to the soil columns. For the CMA4 and CMC4 treatments, N was applied in an organically based form, that was not readily leachable. Cl^- however was applied in a solution form, a readily leachable form. This suggests that the pattern of N leaching losses are affected by the form of N applied to the soils. Cameron & Hayens (1986) indicated that the organically combined N in the manure must be mineralised before it is available to plants or subject to leaching, suggesting that the form of the applied N has some effect on its leaching losses.

Such observations imply that synchronisation of N mineralised from the applied FYM with N plant needs is of great value in reducing the N leaching losses. NO_3^--N leaching losses during winter under the climatic conditions of north-west Europe were observed when mineralisation of organic materials (soil organic matter plant or animal residues) was poorly synchronised with plant uptake (Powlson, 1993). Smith & Chambers (1993) suggested that better timing and sensible rates of applications in relation to crop N requirements are among the key areas need improvement to increase the efficiency of nutrient utilisation from organic manures.

In conclusion, the Cl^- test demonstrated that the pattern of the Cl^- BTC is similar to NO_3^--N BTC for the CMC4, the continuously wet treatment. The drying process affected the shape and the start of the NO_3^--N BTC. Less cumulative effluent was required for the drier columns to start the NO_3^--N BTC than the wetter. NO_3^--N must be mineralised from the applied FYM before it is available to be used by plants or lost by leaching.

4.2- RESULTS OF THE POTS EXPERIMENT:

As already indicated (Section 1.3), this experiment consisted of two pot studies, the FYM study and the urea study. Both studies were carried out to investigate the nitrification process in the applied FYM and urea mixed with sand inoculated by a field soil under different wetting conditions (Section 1.3.2).

The inoculation was achieved by mixing the sand with the sandy loam field soil as the source of nitrifying bacteria (Section 3.2.2). In both the FYM study and urea study, water was intermittently applied to the pots every 4, 8, and 12 days (Table 5.3) on the basis of their weight differences (Sections 2.2 and 3.2.2).

This section aims to discuss the results of the pot experiment under the following headings:

1- The results of N recovered.

2- The results of total soluble salts (EC) and acidity (pH).

4.2.1- The results of N recovered:

As indicated earlier (Section 3.2.2), effluent samples collected from the pots of the FYM and urea studies were analysed for NO_3^--N, NH_4^+-N, and TSN as time series analysis. Bulked samples made for each replicate of both studies were also analysed for NO_3^--N, NH_4^+-N, and TSN. After the experiment ceased, TN was determined in the soils. This section discusses these results under the following headings:

A- Leached NO_3^--N.

B- Leached NH_4^+-N.

C- N in effluent.

D- N budgets.

4.2.1.A- NO_3^--N leached:

The mass of NO_3^--N (mg) recovered in the effluent collected from both studies is summarised in Figure 5.14 for the FYM study treatments (PFM4, PFM8, and PFM12) and Figure 5.15 for the urea study treatments (PUM4, PUM8, and PUM12). Both figures show that NO_3^--N was found in the FYM and urea studies, indicating that nitrification had occurred.

This gives weight to the conclusion drawn in previous pot studies (Chapters 3 and 4), which suggested that the lack of nitrifying bacteria was the reason for no observed NO_3^--N transformation from the applied FYM or urea treatments.

Both figures also show that the peaks of NO_3^--N occurred in the first few wetting events followed by a stage of slow NO_3^--N transformation. This confirms the findings of N residual in the soil columns (Section 4.1.4.A), which suggest a decrease in NO_3^--N concentrations of effluent draining from the columns, as leaching proceeds.

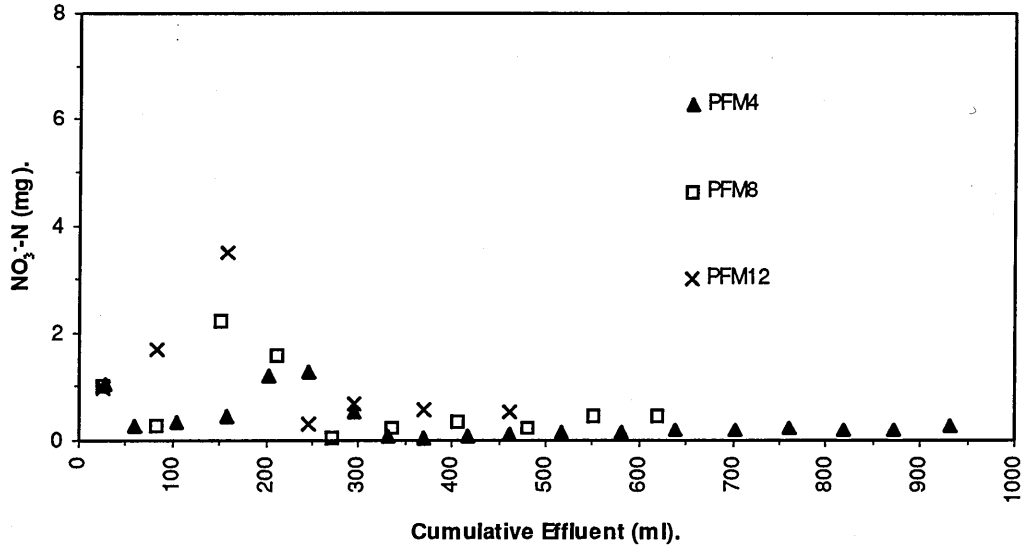


Figure 5.14. Mass of NO_3^--N recovered from the pots of the FYM study treatments.

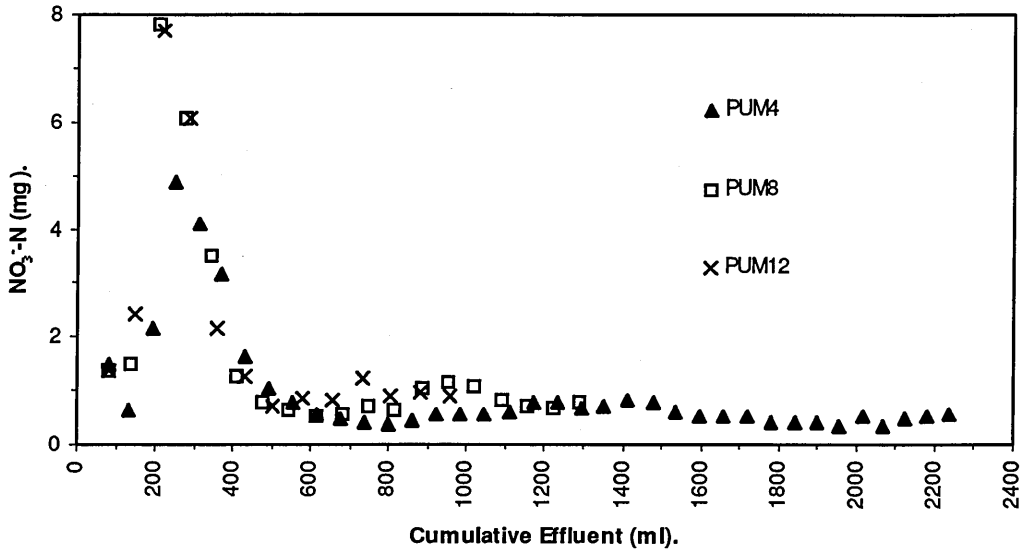


Figure 5.15. Mass of NO_3^--N recovered from the pots of the urea study treatments.

The values of NO_3^--N peaks for the FYM study were smaller than for the urea study. For the FYM study, the peak values were 1.28, 2.23, and 3.51 mg NO_3^--N for the PFM4, PFM8, and PFM12 treatments, respectively (Figure 5.14). For the urea study, they were 4.89, 7.82, and 7.70 mg NO_3^--N for the PUM4, PUM8, and PUM12 treatments, respectively (Figure 5.15). This is attributed to differences is ammonia (NH_3) volatilisation, as will be discussed (Section 4.2.1.C).

4.2.1.B- NH_4^+-N leached:

Figures 5.16 and 5.17 summarise the mass of NH_4^+-N (mg) recovered in effluent collected from the FYM study treatments (PFM4, PFM8, and PFM12) and the urea study treatments (PUM4, PUM8, and PUM12), respectively.

Similar to the NO_3^--N results (Figures 5.14 and 5.15), the peaks of NH_4^+-N occurred in the first few wetting events followed by a slow ammonification for the FYM study (Figure 5.16) and the urea study (Figure 5.17). This indicates that the easily decomposed N compounds of the applied FYM were mineralised during the first events of water application, which occurred in early weeks of the experiment. This agrees with the findings by Saviozzi, ***et al.*** (1995), who observed that the easily

degraded fractions were mineralised in the first month of one year incubation (Section 4.4.1.A).

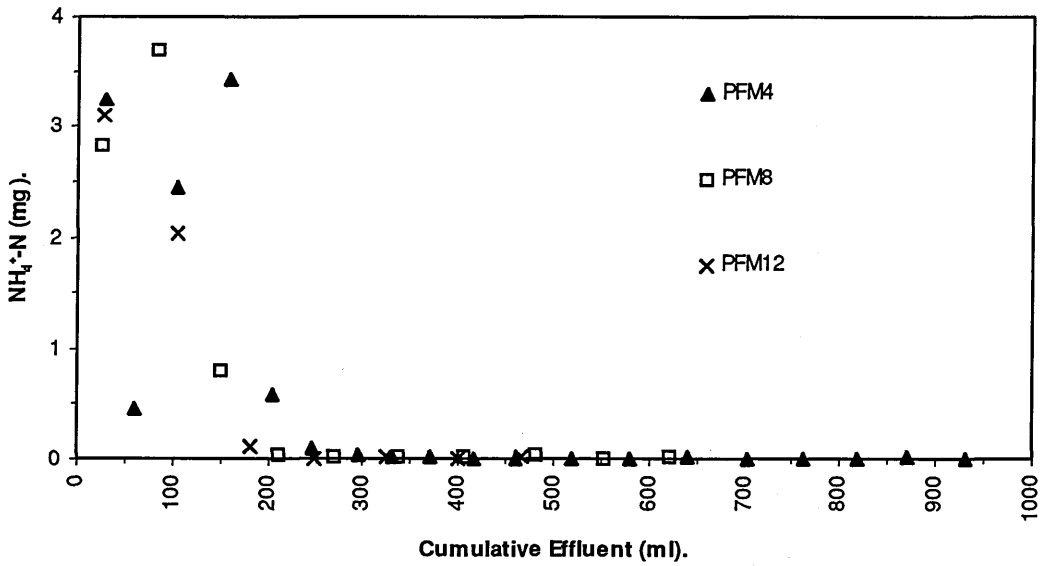


Figure 5.16. Mass of NH_4^+-N recovered from the pots of the FYM study treatments.

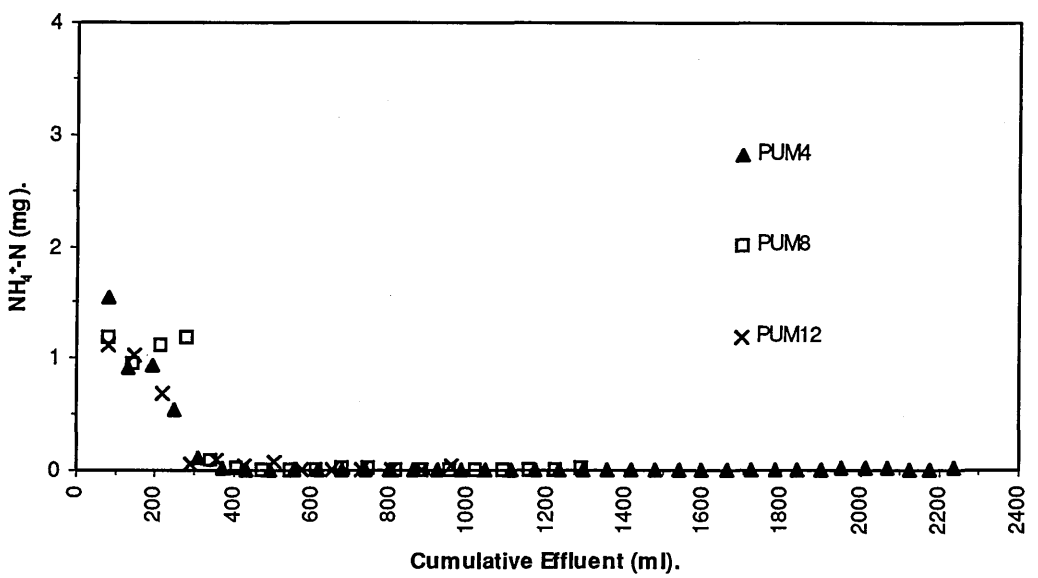


Figure 5.17. Mass of NH_4^+-N recovered from the pots of the urea study treatments.

Figure 5.16 also shows that the values of NH_4^+-N peak were 3.41, 3.70, and 3.09 mg for the PFM4, PFM8, and PFM12 treatments, respectively. For the urea study, the values were 1.55, 1.19, and 1.11 mg for the PUM4, PUM8, and PUM12 treatments,

respectively (Figure 5.17). This shows that the peak values were higher for the FYM study treatments than the urea study treatments. For the NO_3^--N peaks however the differences between the studies were in reverse, which indicates that N mineralisation was a rapid process in the urea study, agreeing with the suggestion by Gould, ***et al.*** (1986).

This is explained by differences in the C:N ratio between both studies. For the urea study, urea had a C:N ratio of 0.43, which was a narrower than the 16.65 value for the FYM study (Section 2.3). Also organic materials are known for their slow N mineralisation. Tisdale, ***et al.*** (1990) indicated that in a period of 15 weeks at best only about 50% of the total N contained in natural organic materials was converted to a form available to plants under conditions optimum for nitrification. During the period, 80% of the N mineralised was converted to NO_3^--N at the end of first three weeks.

These findings indicate that N leaching from a field applied FYM under irrigation is crucial in between the first irrigations. Thus these irrigations require good planning to achieve N best management, which aims to maximise N uptake by plants and minimise N loss.

4.2.1.C- N in effluent-summary:

Different forms of N recovered in effluent collected from both studies are summarised in Table 5.8. The table also includes the results of bulked samples analysis for NO_3^--N, NH_4^+-N, and TSN.

Table 5.8 shows that differences in N results between time series analysis and bulked sample analysis were small. This suggests that bulking samples is an acceptable method to obtain reliable results for N analysis.

For both studies, differences in NO_3^--N and NH_4^+-N results (Table 5.8) were in agreement with those observed for values of NO_3^--N peaks (Figures 5.14 and 5.15) and NH_4^+-N peaks (Figures 5.16 and 5.17). This is due to differences in the properties of N sources used in both studies, as discussed earlier (Section 4.2.1.B).

Similar to NO_3^--N results (Section 4.2.1.A), TSN values for the urea study treatments were higher than the FYM study treatments (Table 5.8). This is explained

by differences in N gaseous loss between both studies, as will be discussed in the following Section 4.2.1.D.

For both studies, TSN values were higher than the sum of NO_3^--N and NH_4^+-N. For the FYM study, TSN values were 3 to 4 times higher than mineral N. They were also twice as high the sum of mineral N for the urea study.

This contrasts with the N results measured in the effluent leached from the soil columns, wherein NO_3^--N was the primary form of N (Sections 4.1.3.A & B). Thus in the leaching columns, it is presumed that some microbes were transported from the top sections of the soil columns containing the applied FYM to the layers underneath. These microbes converted the N ammonified or solubilized from the applied FYM to NO_3^--N before it was leached out of the columns. This suggests that NO_3^--N is the dominant N form leaching beyond the root zone of a field containing applied FYM, which is supported by the findings of other investigators as already discussed (Section 4.3.1.B).

Table 5.8. Summary of different N forms recovered in effluent from both FYM and urea studies.

The Study		FYM			Urea		
Wetting treatment		PFM4	PFM8	PFM12	PUM4	PUM8	PUM12
Time Series Analysis in (mg)	NO_3^--N	6.86	6.82	8.26	35.06	31.51	27.37
	NH_4^+-N	10.36	7.47	5.26	4.18	4.58	3.13
	sum	17.22	14.29	13.52	39.24	36.09	30.50
	TSN	68.28	53.42	49.58	82.49	80.74	75.06
Bulked Samples Analysis in (mg)	NO_3^--N	7.03	6.90	7.60	37.46	30.06	27.04
	NH_4^+-N	11.61	7.78	5.57	4.62	5.09	3.49
	sum	18.64	14.68	13.17	42.08	35.15	30.53
	TSN	71.56	56.65	51.85	83.23	78.68	73.93

Table 5.8 also shows that the total mineral N and TSN decreased as the wetting-drying intervals increased. This is due to the effects of moisture conditions on N mineralisation. Riechman, ***et al.*** (1966) suggested that soil N mineralisation was proportional to soil water content as matric suction increased from 0.2 to 15 bar. Miller & Johnson (1964) also suggested that amount of N mineralised tends to decline exponentially as the optimum matric suction for N mineralisation (0.15 to 0.5 bar) progresses to 15 bar.

Mazzarino, ***et al.*** (1991) indicated that microbial biomass N and N mineralisation increased markedly with the onset of rainfall after being low in the dry season. Mazzarino, ***et al.*** (1991) also observed that the densities of ammonifiers correlated significantly with soil moisture ($P < 0.001$) and N mineralisation ($P < 0.05$), but nitrifiers did not.

The observed relationship between the amount of N mineralised and the drying conditions for both studies agrees with the N results found for the leaching column experiment (Table 5.7, Section 4.1.3.C). This shows that N mineralisation is affected by the wetting-drying strategy adopted in both experiments.

4.2.1.D- N budgets:

The N budgets for both studies are shown in Table 5.9. The table includes TN at the start, TN after the experiment ceased, N recovered in effluent, and differences between them representing the N not-accounted for, which was assumed to be losses in the form of gaseous N compounds. The TN at the start was the TN of the mixture materials used for each study (Table 5.2, Section 2.1). The N recovered in effluent was the values of TSN for the bulked samples (Table 5.8).

Though N losses in the form of gaseous compounds are of major concerns due to their effects on air pollution and the consequences of global heat and environmental damage (Van Breemen, ***et al.***, 1982; Bouwman, 1989; Conway & Pretty, 1991; DOE, 1994), it was not possible to study these N losses. The relatively high percentage of N not-accounted for (especially for the FYM study) however formed attention on the need to investigate these losses.

Table 5.9. The Summary of N Budgets for both studies of the pot experiment.

The Study		FYM			Urea		
Wetting treatment		PFM4	PFM8	PFM12	PUM4	PUM8	PUM12
TN at the start	(mg)	644.82	644.82	644.82	239.80	239.80	239.80
TN at the end	(mg)	431.89	416.65	443.21	146.88	146.42	143.06
N Recovered	(mg)	71.56	56.65	50.85	83.23	78.68	73.93
N not-accounted for	(mg)	141.37	171.52	150.76	9.69	14.7	22.81
	(%)	21.92	26.60	23.38	4.04	6.13	9.51

The un-accounted N was thus assessed by a model modified by Whitehead & Raistrick (1990). The model suggests that the percentage of NH_3 volatilised from N compounds can be estimated by the pH value of the compounds after 24 hours of incubation. Their model is given as:

$$V = -4.61 + 0.0324\ (2.465)^{n}$$

where V is the percentage of NH_3 volatilised, and **n** is the pH of the N compound determined after 24 hr incubation.

Three replicates for each study were used to estimate the percentage of NH_3 volatilised (V) by the model. The V values were 19.82% (±0.39) and 6.21 (±0.23) for the FYM and urea studies, respectively. This indicates that the un-accounted N was NH_3 volatilised from the pots, which is a reasonable suggestion as there was a strong odour of NH_3 in the incubating room during the first few wettings.

Table 5.9 shows that the values of un-accounted N for the FYM study were higher than the values for the urea study. This is a result of urea incorporation into the surface of the mixed sand with sandy loam field soil (Section 2.1). Urea incorporation into the soil surface was found to reduce NH_3 volatilisation (Terman, 1979; Nelson, 1982; Jayaweera & Mikkelsen, 1991). Ernst & Massey (1960) observed that mixing urea with the top 3.8 cm of a neutral soil reduced the NH_3 losses by 75% compared to the surface broadcast.

Thus as already indicated, differences in NH_3 volatilisation between the FYM and urea studies are the possible cause for differences in NO_3^--N peaks (Section 4.2.1.A) and total mineral N and TSN (Section 4.2.1.C).

In conclusion, N results from the pot experiment showed that nitrification occurred in the FYM and urea studies, confirming that nitrifying bacteria were lacking in the FYM-sand mixture in the previous pot studies (Chapters 3 and 4), which inhibited nitrification.

The pot experiment also showed that NH_3 losses were higher from the applied FYM than the incorporated urea. This indicates that when an application of FYM to a field is made proper management is needed to minimise NH_3 volatilisation, which can cause a N loss and air pollution.

For the pot experiment, N results indicated that there was a relationship between N mineralisation and intermittent wetting-drying conditions. It was found that the amount of N leached decreased as the drying conditions increased, which agrees with the conclusion drawn from the N results for the leaching column experiment.

4.2.2- The results of total soluble salts (EC) and acidity (pH):

As stated above (Section 3.2.2), total soluble salts (EC) and acidity (pH) were determined in the time series effluent samples collected from the pots of the FYM and urea studies.

The objective of this section is to discuss the EC and pH results.

4.2.2.A- The EC results:

Figures 5.18 and 5.19 indicate the EC values in effluent collected from the pots of the FYM study treatments (PFM4, PFM8, and PFM12) and the urea study treatments (PUM4, PUM8, and PUM12), respectively.

For the FYM and urea studies, Figures 15.8 and 5.19 show that the EC values were too small to cause toxic conditions for the micro-organisms involved in N mineralisation. McClung & Frankenberger (1985) found that urea ammonification was not apparently affected using salts with concentrations up to 20 dS m^{-1}. This also

agrees with the findings of the leaching column experiment (Section 4.1.5.A) and the previous studies (Chapter 4, EC results).

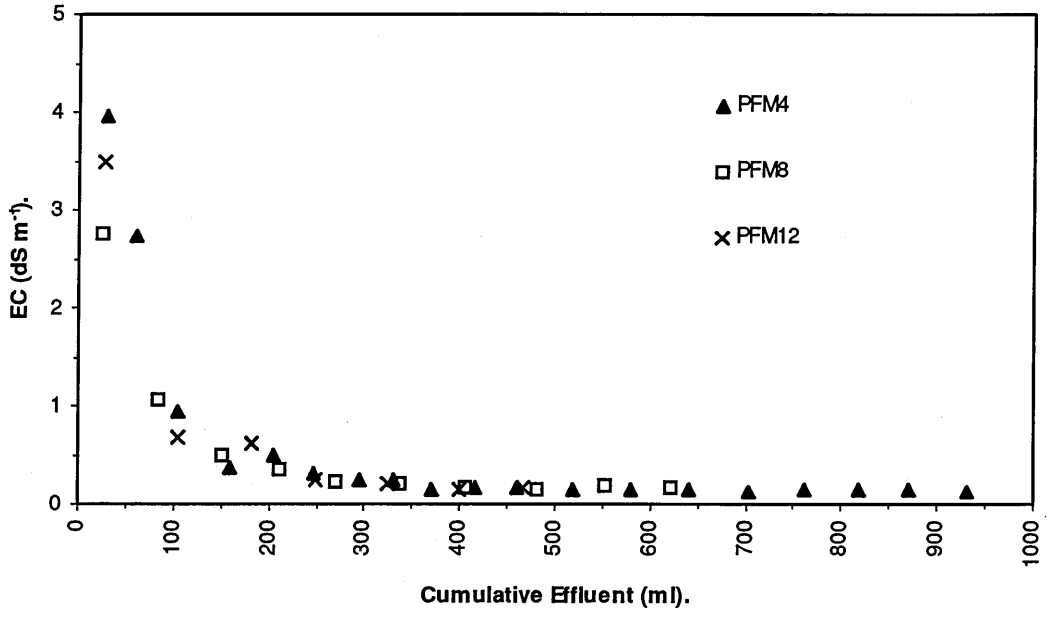


Figure 5.18. The EC values in effluent collected from the FYM study treatments.

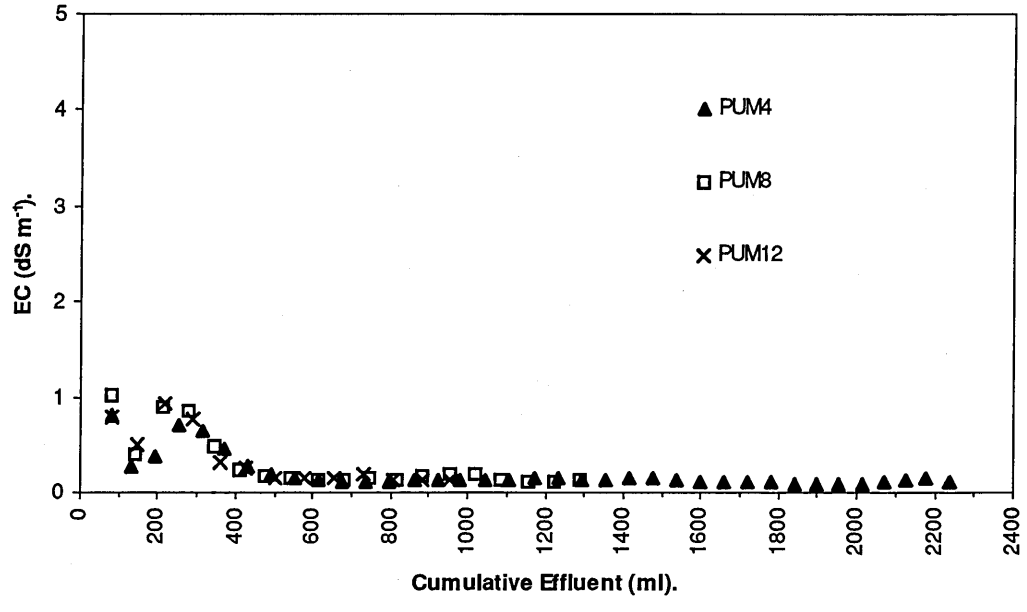


Figure 5.19. The EC values in effluent collected from the urea study treatments.

For the FYM study treatments, the highest EC values were at the beginning of the experiment (Figure 5.18). They were 3.95, 2.76, and 3.5 dS m^{-1} for the PFM4, PFM8,

and PFM12 treatments, respectively. Then the values showed a decreasing trend for all the treatments, with EC becoming less than 1 dS m^{-1} after 2 to 3 wetting events. For the treatments of the urea study, EC values were ,however, 1 dS m^{-1} or less (Figure 5.19).

This indicates that for the FYM study EC values at the beginning were high enough to possibly injure salt sensitive crops at early stages of growth (Maas & Hoffman, 1977), which suggests that sowing such crops on a field containing applied FYM needs to be properly timed in accordance to these EC values.

4.2.2.B- The pH results:

The pH values in effluent collected from the pot experiment are shown in Figure 5.20 for the PFM4, PFM8, and PFM12 treatments of the FYM study and Figure 5.21 for the PUM4, PUM8, and PUM12 treatments of the urea study.

Both figures show that the pH values were high at the beginning of the experiment, decreasing afterwards. For the FYM study, the pH values were 8.30, 8.53, and 7.91 for the PFM4, PFM8, and PFM12 treatments, respectively. They were 8.68, 8.89, and 8.67 for the PUM4, PUM8, and PUM12 treatments of the urea study, respectively. NH_3 volatilisation was observed to be high at such pH values (Nelson, 1982; Adams & Martin, 1984; McClung & Frankenberger, 1985; Haynes & Sherlock, 1986).

Addiscott, ***et al.*** (1991) indicated that NH_3 losses occur mainly in soils that are already alkaline and during weather causing the soils to dry (i.e., warm and windy weather). Adams & Martin (1984) and McClung & Frankenberger (1985) suggested that an increase in soil pH increases NH_3 losses. Nelson (1982) indicated that the influence of soil pH on the proportion of applied urea or NH_4^+ volatilised as NH_3 is explained by the effect of H^+ concentration on the NH_4^+-NH_3 equilibrium in soils.

In conclusion, the results of this section showed that N mineralisation in both the FYM and urea studies was not inhibited by the values of EC or pH. NH_3 volatilisation was probably as a result of the high pH values at the beginning of the experiment. Differences in amount of NH_3 volatilised between both studies were attributed to urea incorporation.

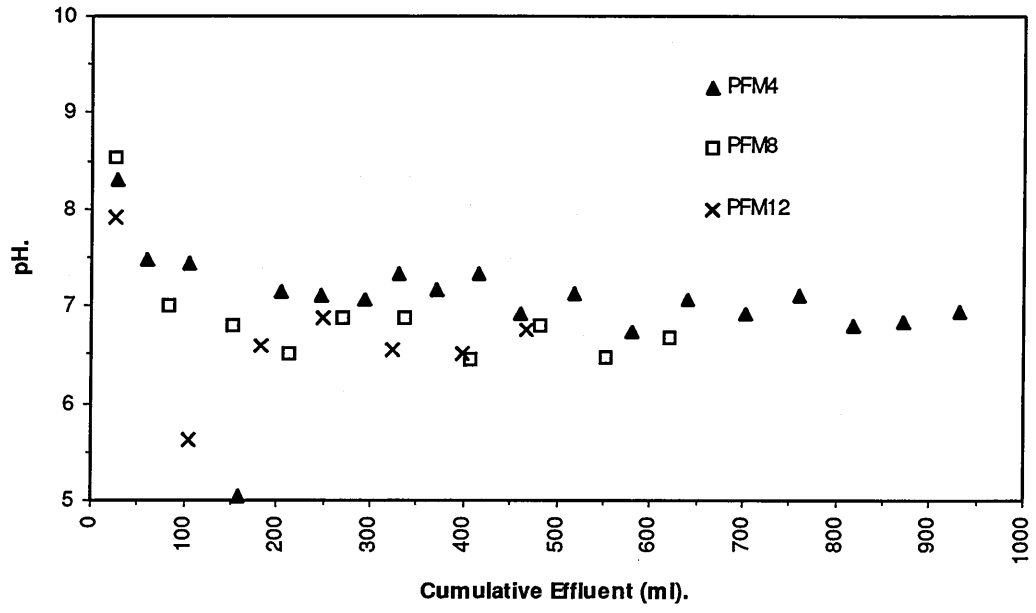


Figure 5.20. The pH values in effluent collected from the FYM study treatments.

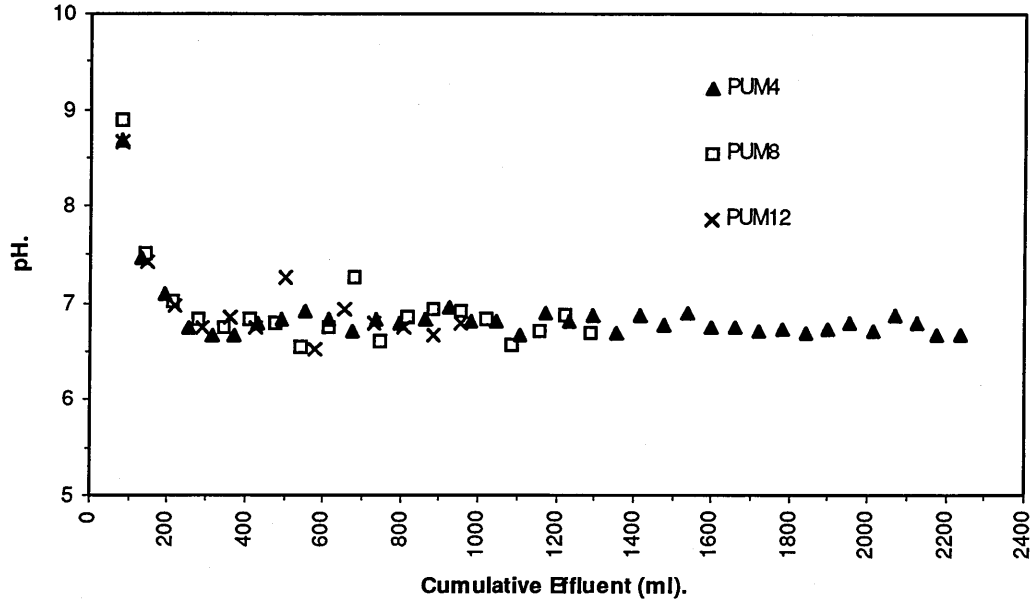


Figure 5.21. The pH values in effluent collected from the urea study treatments.

5- CONCLUSION:

In irrigation practices, water is applied to provide growing crops with their water requirement. It was however observed from this study that water application is an important factor in determining the amount of N mineralised from FYM, which implies

that N utilisation from FYM applied to the field must be considered in the irrigation management, so improving the N use efficiency.

The data obtained from the leaching column and pot experiments conducted showed there was a relationship between the amount of N mineralised from the applied FYM and water application, as expected. The maximum amount of N mineralised was found at the FC moisture condition, then decreasing as the drying condition increased. This implies that the amount of N mineralised from the FYM applied to a field under irrigation is influenced by the moisture conditions provided by irrigation practices.

The N results in the leaching column experiment also demonstrated that NO_3^--N transport throughout the soil columns was related to water application. The water applied-collected relationship resulting from the wetting strategy adopted, caused differences in the pattern of NO_3^--N leaching losses. This suggests that water application management is a key factor to control NO_3^--N movement in and out of the soil profile.

The leaching losses of N from soil columns were mainly in the form of NO_3^--N, with concentration exceeding the required limit for the domestic water supplies (11.3 mg NO_3^--N l^{-1}) for all the treatments.

The pot experiment showed high N losses by volatilisation from the applied FYM. These losses occurred during the first wetting events as seen by the change in pH values.

During this period, the majority of N mineralisation also occurred. Salinity as measured by EC was high enough to injure a sensitive crop at early stages of growth. This shows that applying FYM to a field under irrigation requires good planning for water application, especially to the first in-between irrigations, to ensure best N management. Thus, N will be utilised by the growing crops and leaching losses minimised, although it may not be possible to reduce NO_3^--N leaching losses to zero on sandy soils as suggested by Watts & Martin (1981), who have provided guideance on irrigation scheduling to minimise deep percolation rates and reduce NO_3^--N leaching losses.

CHAPTER SIX

DISCUSSION AND CONCLUSIONS

INTRODUCTION:

The study aimed to examine the leaching loss of N mineralised from applied FYM and N fertilisers under a simulated centre pivot irrigation practices. The study consisted of three experiments using pots and leaching columns (Chapters Three, Four, and Five). The objective of this chapter is to discuss the results of the experiments carried out in this study and their implementation. The discussion considers the following topics:

1- A farm case of irrigation practices.
2- Irrigation and N mineralisation.
3- Leaching practices and N loss.
4- Recommendations.
5- Further investigations.

1- A FARM CASE OF IRRIGATION PRACTICES:

As stated in Section 4.2 of Chapter One, the purpose of irrigation is to apply water to soil to meet the plants water requirements. The quantities and intervals of water application are scheduled to maintain moisture conditions in the effective rooting zone at levels optimum for plants growth and production. These levels are usually allowed to vary between FC and 50% of the available water in the root zone (Section 4.2.A, Chapter One).

An example, demonstrating a centre pivot irrigation plan for wheat grown in the Gassim region of the KSA is given in Table 6.1. The table includes the gross daily irrigation requirements, which were calculated from the monthly net water requirements estimated by the modified Penman method (AL-Zeid, ***et al.***, 1988). Leaching efficiency, leaching fraction, and irrigation efficiency are adapted from AL-Zeid, ***et al.*** (1988). The planting date and the length of growing season have been selected on the basis of the experience of Gassim Agricultural Company (GAC, 1987). The resulting moisture conditions are illustrated in Figure 6.1.

Figure 6.1 shows that different irrigation schedules can be used to apply intermittently the gross daily irrigation requirements. The first is to apply water in low

quantities and high frequency (high frequency irrigation). The second is to apply water in large quantities and low frequencies (low frequency irrigation). Where the second plan is practiced an appreciable amount of available water holding capacity (AWHC) is allowed to be depleted by plants. In this example, the depth of AWHC is assumed to be 60 mm, an average value for the coarse sand soils (Martin, ***et al.***, 1990).

These irrigation practices illustrate that moisture conditions in the surface layer containing the applied FYM are affected by irrigation scheduling (Figure 6.1). These conditions can be maintained at or close to FC by high frequency irrigation (First plan), or oscillated between wet and dry conditions by low frequency irrigation (Second plan). This work has shown that variations in moisture conditions have impacts on N mineralisation, which implies that irrigation scheduling is a key practice determining the amounts of N mineralised from the FYM applied to a field irrigated by a centre pivot.

Table 6.1. The daily gross irrigation requirements for wheat grown under centre pivot in Gassim area, KSA (GAC, 1987; AL-Zeid, ***et al.***, 1988).

Average planting date: 15 Dec. (8-22 Dec, GAC, 1987).

Average length of growing season: 120 days (15 Dec. to 14 April).

Leaching efficiency: 90%.

Irrigation efficiency: 70%.

Leaching fraction: 0.09 (water salinity is 3.12 dS m^{-1}).

Average effective rooting depth: 1 m.

Water applied	Dec.	Jan.	Feb.	Mar.	Apr.
Net water requirements (m^3/ ha/ month)	278	787	1379	1944	605
Net water requirements (mm/day)	1.74	2.54	4.67	6.48	4.32
Irrigation requirements (mm/day)	2.96	4.32	7.94	11.02	7.34
Leaching requirements (mm/day)	0.27	0.39	0.71	0.99	0.66
Gross irrigation requirements (mm/day)	3.23	4.71	8.65	12.01	8.00

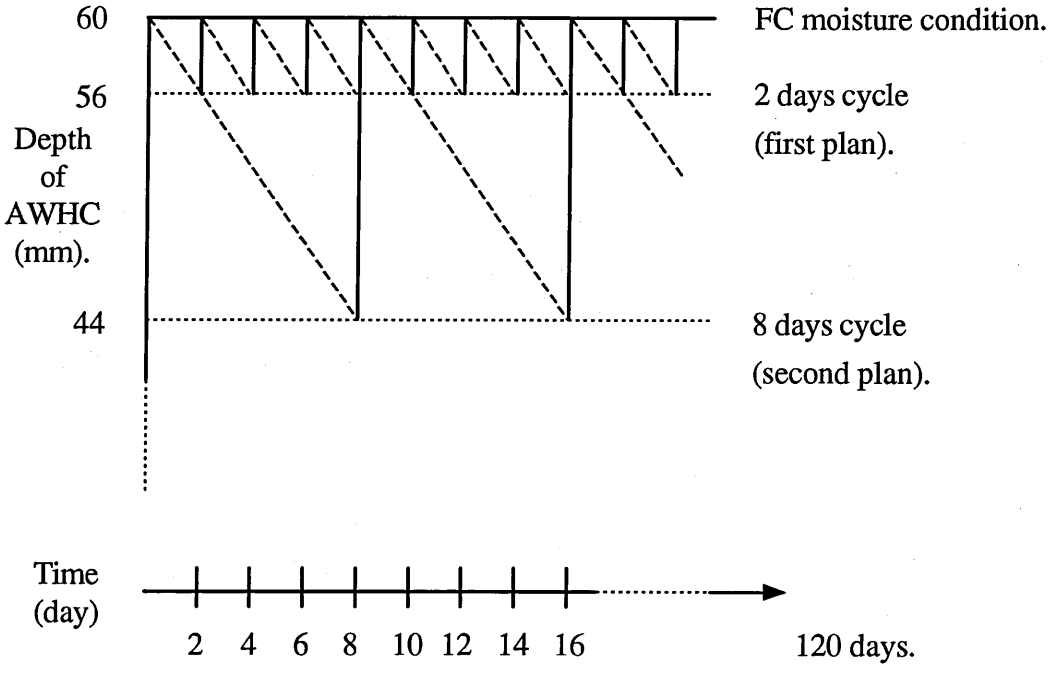


Figure 6.1. Different irrigation schedules for wheat grown in the Gassim area, KSA.

2- IRRIGATION AND N MINERALISATION:

From this study, it can be concluded that the contrasting soil moisture conditions caused by the different wetting treatments adopted significantly affect ($P < 0.05$) N mineralised from the applied FYM. In Experiments One and Two, the wetting treatments caused significant differences ($P = 0.05$) in the peak values of NH_4^+-N mineralised (Sections 4.2.1 and 4.3.1 of Chapters Three and Four, respectively). The highest values were found under the M1 treatment, 2 days wetting-drying regime (Tables 3.5 and 4.11, Chapters Three and Four, respectively). Also, there were significant differences ($P = 0.05$) between the peaks of NO_3^--N leached from the soil columns (Section 4.1.3.A, Chapter Five). These results are in agreement with the findings of other investigators, as already discussed in the Sections mentioned.

The relationship between N transformation and moisture conditions suggests that the amounts of N released by microbes from the applied FYM are influenced by the moisture condition provided by irrigation practices. This is most likely due to effects

of the soil moisture conditions resulting from irrigation on the microbial population and activity (Buyanovsky, ***et al.***, 1982; Kubista, ***et al.***, 1988).

The implications of this relationship between irrigation and microbial activity and population are that microbial N mineralisation from the applied FYM is likely to be maximised when irrigation is managed to maintain soil water content at or close to FC. This is well illustrated in Experiment Three by the results of NO_3^--N BTC (Figure 5.7, Section 4.1.3.A, Chapter Five). The results demonstrated that the highest value of NO_3^--N concentration leached from the soil columns (95.09 mg NO_3^--N l^{-1}) was observed for the CMC4 treatment which had the top sections containing the applied FYM maintained continuously at FC.

In irrigated fields by centre pivot systems, this irrigation management is accomplished by adopting the first irrigation plan demonstrated in the given example in the previous Section of this Chapter (Figure 6.1).

However, when a partial depletion of AWHC is allowed by choosing the second irrigation plan (Figure 6.1), drying conditions near the soil surface will occur in-between irrigations. These drying conditions will decrease microbial activity and hence the amounts of N mineralised from the applied FYM, which can be seen from the results obtained in the current study.

During the drying periods in between irrigations, however, soil micro-organisms responsible for N transformation have the capability of surviving, and they are expected to mineralise the organic N in the applied FYM. The capability of the micro-organisms to survive and to transform N under dry conditions has already been discussed in details in Sections 4.1.1.A and 4.1.2 of Chapter Five.

Micro-organisms, in fact, are able to survive drier conditions than those normally found in-between irrigations. This is shown by the results obtained in the study undertaken where air dried FYM and field soil were used. In agreement with other workers, it has been shown that micro-organisms have the capability of going into desiccation periods and resuming their activity shortly after water application (Section 4.1.2, Chapter Three).

Despite the irrigation plan used, previous discussion indicates that N mineralisation is an active process in cultivated fields under irrigation. Providing organic materials are available (i.e., whether indigenous or applied), N mineralisation is a significant source of mineral N in the soil solution (i.e., especially in NO_3^--N form), which might be utilized by plants. The concern therefore is that the amount of mineralised N exceeds the capacity of crops to utilize it (Sommerfeldt, ***et al.***, 1988).

Though no plants were grown in this study, it should be emphasized that plant uptake is the primary objective of N fertilisation practices. However, a total removal of N from the soil solution by plants is rare (Allison, 1966; Keeney, 1982; Gilliam, ***et al.***, 1985; Hallberg, 1986). In a single harvested crop grown under the best field conditions, N recoveries are not likely to be greater than 50 to 75% and often much below these values (Allison, 1966). This suggests that considerable amounts of N in soil solution are not utilised by the plants, posing a risk to leach from the root zone.

It has been suggested by other investigators that plant uptake is an indispensable process reducing the NO_3^--N loss by leaching (e.g., Long & Huck, 1980 ; Stevenson & Neilsen, 1990; Christian, ***et al.***, 1992; Schröder, ***et al.***, 1992). However, N mineralised from the FYM applied under irrigation is likely to elevate mineral N in soil solution at times when the plants do not require N.

For instance, Schröder, ***et al.*** (1992) indicated that NO_3^--N concentrations in the upper groundwater exceeded the EC-standard for drinking water, despite the 50% reduction caused by winter cover crops. Also, Stevenson & Neilsen (1990) observed in a study carried out for 9 years using irrigated orchard-type lysimeters that the first year drainage carried substantial amounts of NO_3^--N out of the lysimeters as a result of mineralised native organic N plus applied N fertiliser.

It was also observed in this study that the application of urea-N fertiliser to the FYM-sand mixture increased the amounts of mineralised N recovered in the effluent (Section 4.3.5, Chapter Four), which was due to the addition of urea and decreased C:N ratio of the applied FYM. During decomposition, organic materials with a narrow C:N ratio release N more readily than those with a wide C:N ratio (Section 3.2.1, Chapter One). This implies that agricultural activity involving the addition of urea with the applied FYM increases the risk of NO_3^--N leaching loss.

It is possible to conclude from this section that the amount of mineralized N from the applied FYM is affected by the irrigation practices chosen. The mineralised N increases the concentration of NO_3^--N in soil solution. The growing crops may be able to remove this NO_3^--N from the solution, which otherwise may leach from the root zone. The loss of NO_3^--N by leaching has an economic value that adversely affects the farmers' returns. Also, it poses a risk to the environment. In addition to NO_3^--N concentration in the soil solution, however, NO_3^--N leaching loss depends on the volume of water draining out of the root zone, as will be discussed in the following section.

3- LEACHING PRACTICES AND N LOSS:

The amount of NO_3^--N that leaches from the root zone has been observed to be a function of the volume of drainage water and the amount of leachable NO_3^--N in the soil solution. These relationships have been discussed in Sections 4.1.1.B, 4.1.2, and 4.1.6 of Chapter Five.

The movement of NO_3^--N in the soil columns was observed to correlate with water application frequency (Section 4.1.2, Chapter Five), which demonstrates the effects of irrigation practices on NO_3^--N redistribution in the soil profile after being mineralised from the applied FYM.

In section 4.2.B of Chapter One, it has been suggested that good management of both irrigation and N supply reduces NO_3^--N loss by leaching. Irrigation management should aim to minimise deep percolation rates, although leaching is a beneficial process required to prevent the adverse effects of salinity and its associated hazards on crops.

Stevenson & Neilsen (1990) stated that soluble NO_3^--N apparently leaches from the soil profile in large quantities by large volumes of drainage resulting from large applications of irrigation water. The relationships between irrigation practices and leaching loss of NO_3^--N have also been studied by other investigators (Raveh & Avnimelech, 1973; Hahne, ***et al.***, 1977; Letey, ***et al.***, 1977; Smika, ***et al.***, 1977; Bauder & Montgomery, 1980; Watts & Martin, 1981; Feigin, ***et al.***, 1982; Keeney, 1982; Bouwer, 1987; Abu Awad, ***et al.***, 1988; Ritter, 1989; Miller & Anderson, 1994).

The present study has indicated that NO_3^--N leaching loss is affected by the volume of drainage water, agreeing with the findings of other workers. In the leaching columns of Experiment Three (Chapter Five), the wetting treatments had different values of N loss rates (primarily in NO_3^--N form) (Table 5.7), which were ascribed to the differences in the Y/X values between the treatments (Table 5.5). For instance, the CMC4 treatment had the highest values of the Y/X (0.93) and N loss rate (0.94 mg N d^{-1}) compared with the 0.57 and 0.15 mg N d^{-1} found for the CMA12 treatment, respectively.

This implies that the NO_3^--N leaching losses may be reduced by minimising the volume of drainage water, which could be achieved by reducing the rates of irrigation and proper scheduling. Keeney (1982) suggested that lowering irrigation rates is one management practice that would seem desirable at least from the standpoints of total N loss by leaching or by denitrification. Watts & Martin (1981) stated that irrigation scheduling to minimise deep percolation rate reduces leaching losses of NO_3^--N.

The management practice of using low irrigation rates can be accomplished by high frequency applications of small quantities using a centre pivot (First irrigation plan, Figure 6.1). Under such water application practices, water and soluble salts (i.e., including soluble N) have been observed to advance in the soil profile (Biggar & Nelisen, 1967; Kirda, ***et al.***, 1974), which suggests that these salts can be reserved in the root zone for the plants to utilize, providing proper management of drainage practices. Such a relationship has been also observed in this study (See, Figures 5.4 to 5.6 , Section 4.1.2, Chapter Five).

This irrigation practice is also likely to maintain the water content in the soil profile at wet conditions (i.e. at FC), which may retard the movement of NO_3^--N as suggested by other investigators (Edwards, ***et al.***, 1972; Balasubramanian, ***et al.***, 1976; Singh, ***et al.***, 1984). The retarded movement of NO_3^--N in the wet condition has been observed in this study (Sections 4.1.3.A and 4.1.6 of Chapter Five). For the wettest treatment (CMC4), 812.33 ml cumulative effluent was required for the NO_3^--N to reach breakthrough compared to the 380.67 ml required for the driest treatment (CMA12). This implies that larger volumes of cumulative effluent are required to leach the NO_3^--N out of the soil profile under the wet conditions than under the dry

conditions, which suggests that the chance for the plants to utilize the NO_3^--N in the soil solution is better under the wet conditions than under the dry ones, provided there are no other constraints on the plants.

The FC moisture condition has been observed to be the optimum for root activity, which suggests that N plant uptake is likely to be at its greatest (Viets, 1967; Tisdale & Nelson, 1975; Foster, ***et al.***, 1995). Viets (1967) for instance stated that all evidence indicates that uptake of nutrients by plants is most favoured at low soil water suction.

In contrast, where the second irrigation plan is practiced (Figure 6.1), the drying conditions in-between irrigation will presumably lessen root activity, reducing N uptake by the plant, as observed by other workers (Humphreys, ***et al.***, 1989a, 1989b).

Notwithstanding this, as already concluded in Section 5 (Chapter Five), it has been suggested that zero leaching loss of NO_3^--N is not likely to be possible in many cases. For economic and environmental reasons, however, the NO_3^--N leaching loss ought to be kept at the lowest possible levels, commensurate with practical management.

It has been reported that NO_3^--N leaching leads to surface and ground water contamination (Hill & McCague, 1974; Singh & Sekhon, 1979; Gormly & Spalding, 1979; Hallberg, 1986; Bouwer, 1987; Schmidt & Sherman, 1987; Hubbard & Sheridan, 1989; Cooke, 1974; Logan, 1990; Burt & Trudgill, 1993; Spalding & Exner, 1993). A major difference between the two cases is that groundwater contamination is a long term process. For instance, a lag time of many years may be required before the leached NO_3^--N reaches the groundwater body (Pratt, ***et al.***, 1972; Keeney, 1982, Croll & Hayes, 1988; DOE, 1988). Under citrus on the alluvial materials of the Santa Anna River Basin, Pratt, ***et al.*** (1972) indicated that a lag time of 10 to 50 years would be required for the excess NO_3^--N in the soil surface in any one year to reach the 30 m deep well waters. For the water up to 40 m deep, Croll & Hayes (1988) stated that the NO_3^--N contained in the water currently being pumped from boreholes has been leached from the soil surface since 5 to 40 years ago.

Among the factors that determine the magnitude and time rate for groundwater contamination is the N fertilisation practice (Singh & Sekhon, 1979; Robertson, 1979; Hallberg, 1986; Sabol, ***et al.***, 1987; Hubbard & Sheridan, 1989; Knox & Moody,

1991). Besides N fertilisers, N mineralisation was found to be a substantial source of leaching NO_3^--N (Addiscott, 1988 & 1991; Macdonald, ***et al.***, 1989; Johnston, 1994). Macdonald, ***et al.*** (1989) indicated that almost all of the NO_3^--N at risk to leaching loss during the winter season comes from mineralisation of organic N, not from the unused fertiliser applied in spring.

Thus, this shows that failure to make proper adjustment for the N mineralised from the applied FYM will cause an increase in NO_3^--N leaching loss (Chaney, 1990). It also shows that, for cultivated fields receiving repeated FYM applications, limiting the use of N fertiliser for a short term will possibly not control the contamination of drainage water by leaching NO_3^--N, agreeing with the findings of other investigators (Addiscott, 1988; Macdonald, ***et al.***, 1989, Chang & Entz, 1996). This suggests that besides proper N application, the volume of drainage water needs to be minimised to reduce NO_3^--N leaching loss.

In conclusion, minimising the volume of drainage water by proper irrigation management is perhaps the practice that is most likely to reduce NO_3^--N leaching from a field receiving repeated FYM applications. Such irrigation practices will indeed improve both the WUE and NUE (Keeney & Follett, 1991). Improving NUE is an economic gain and should be a long term strategy to prevent the degradation of groundwater quality. Thus, improving both WUE and NUE is an essential aspect in the KSA because water resources are limited.

4- RECOMMENDATIONS:

Keeney and Follett (1991) stated that the goal of any N management plan must include minimising the leaching of NO_3^--N into groundwater from an agricultural activity. Taking this suggestion into consideration, the recommendations which can be made from the results of this study are:

4.1- IRRIGATION AND DRAINAGE PRACTICES:

From the standpoints of N mineralisation and leaching loss, the discussion in Sections 1 and 2 of this Chapter demonstrates that irrigation and drainage are usually practiced together, which suggests that simple recommendations for best N

management are not feasible. However, some scenarios can be used to clarify which practices may be adopted. The scenarios compare between the NO_3^--N concentration in the soil solution and leaching losses expected under different irrigation scheduling and drainage practices. The two irrigation plans suggested in Section 1 of this chapter (Figure 6.1) are used for these scenarios.

These scenarios aim to obtain the best possible irrigation and drainage practices, which minimise the N leaching losses without subjecting the plants to adverse effects. In these scenarios, it is assumed firstly that there are no significant differences in the amounts of N utilised by the plants under the two irrigation plans, as no stresses are imposed on them. Also, drainage practices allow the minimum possible drainage volumes and low rates of deep percolation.

The discussion of these scenarios is based on the relationships between the irrigation practices and N mineralisation and, between the drainage practices and N leaching loss, which have been already observed in this study. The scenarios are:

Scenario 1. Different irrigation frequencies with the same irrigation efficiency:

Under these practices, the volumes of drainage are equal for the two irrigation plans. The farmer is therefore advised to adopt the second irrigation plan. This is because low irrigation frequency results in low NO_3^--N concentration in the soil solution, which will lead to a small load of N leaching from the soil profile. The following example demonstrates this scenario.

From Table 6.1 of this chapter, the total leaching volume is 449.37 m^3 ha^{-1} (i.e., the net water requirement, 4993 m^3 ha^{-1}, multiplied by the leaching fraction, 0.09). Using the NO_3^--N peak values found for the CMC4 and CMA8 treatments of the leaching columns (95.09 and 50.46 mg l^{-1}, respectively, Figure 5.7, Section 4.1.3.A, Chapter Five), this drainage volume will carry 22.68 kg NO_3^--N ha^{-1} out of the soil profile under the second plan compared to 42.73 kg NO_3^--N ha^{-1} under the first plan.

This shows that irrigating with low frequencies, though high water quantities are applied, will result in a small N load leaching from the soil profile. Nevertheless, irrigation efficiencies are not always the same, which then leads us to the following scenario.

Scenario 2. Different irrigation frequencies with different irrigation efficiencies:

Under these conditions, different irrigation efficiencies will result in different leaching fractions. It is assumed that two leaching fractions are observed (e. g., 0.09 and 0.18) under the two irrigation plans. Table 6.2 summarises the loads of N that leach out of the soil profile under these practices. These loads are calculated using the same data as in the previous example given in Scenario 1.

Table 6.2. Loads of N leaching from a soil profile under different leaching fractions.

Leaching		Amounts of N leached (kg ha-1)	
fraction	volume (m^3 ha^{-1})	First plan (95.09 mg l^{-1})	Second plan (50.46 mg l^{-1})
0.09	449.37	42.73	22.68
0.18	898.74	85.46	45.35

Table 6.2 shows that the decision to make the best possible recommendation depends on both irrigation scheduling and leaching fraction. For instance, the second irrigation plan combined with high leaching fraction (0.18) causes N leaching losses more than the first plan with low leaching fraction (0.09) (45.35 compared to 42.73 kg N ha^{-1}, respectively). Thus, if a farmer is choosing between these practices, it is then advisable to recommend the one causing the least N leaching losses.

Scenario 2 also demonstrates the role of drainage practices and NO_3^--N concentrations in the soil solution resulting from irrigation scheduling on the amounts of N leaching out of the soil profile. It suggests that a knowledge of these two factors may be used to determine the best practices to adopt when significant differences between the amounts of N utilised by plants are observed, which will alter N concentrations in the soil solution. Differences in N uptake by plants may occur as a result of variations in the soil properties of the cultivated fields, the crops, or the climate, which may be considered among the factors used to determine the best possible recommendation to achieve best N management.

4.2- N PRACTICES:

When considering irrigation management, the following points are made:

i- supply the crop with the required amounts of N fertiliser with proper adjustments for N mineralised from the applied FYM.

ii- avoid the addition of any starting N fertiliser during the first few wetting events for the applied FYM.

iii- avoid repeated high application rates of FYM.

iv- incorporate organic materials with a wide C:N ratio such as straw to widen the C:N ratio of the applied FYM. This practice is assumed to enhance N immobilisation during straw decomposition at the beginning of the season when the rooting system of the crop has not yet developed. However, when N starts being remobilised (See Figure 1.2 in Chapter One), roots are developed intercepting the mineralised N. Reduced NO_3^--N leaching losses by incorporated straw have been also observed by other investigators (e.g., Catt, ***et al.***, 1992; Nicholson, ***et al.***, 1997).

4.3- CROP PRACTICES:

Crop rotations should be adopted that ensure NO_3^--N in the root zone is scavenged by the roots. Different investigators have discussed in details the relationships of crop practices with NUE (e.g., Keeney, 1982; Bock, 1984; Kurtz, ***et al.***, 1984).

4.4- GROUNDWATER CONTAMINATION:

To be aware of the possibility of groundwater contamination resulting from improper N practices involving the application of FYM to irrigated fields. Further investigations on this aspect is recommended as will now be discussed.

4.5- SUGGESTED PRACTICES:

The following practices may be recommended to the farmers using FYM:

i- apply the appropriate rate of the FYM to the field. This is decided from the crop N requirement and a knowledge of soil reserves.

ii- incorporate straw materials with the applied FYM into the surface layer.

iii- irrigate with low water quantities and high frequency determined by crop water requirements.

iv- start sowing seeds after 1 to 2 week from the starting wetting event

v- a small dosage of starting N fertiliser may be applied at seeding or a few days later. Further N fertiliser dosages should be applied at timings and quantities according to plant N requirements with considerations to N mineralised from the applied FYM.

5- FUTURE INVESTIGATIONS:

From this study, some aspects are considered important for further investigations:

5.1- N PRACTICES:

There is a need to determine the maximum application rates for N fertiliser and FYM in the KSA, accounting for the wide variations in soil properties and climatic conditions between the different regions. These rates ought to obtain the best relative crop yields and lowest environmental implementations.

5.2- GROUNDWATER PROTECTION:

Water quality conservation is a vital issue nowadays. This issue does not only relate to the countries where water is scarce like the KSA, but also it relates to all countries including those where water is abundant.

The widespread interests in this issue come from the fact that groundwater may require many years to become contaminated as already discussed. Once contaminated, it may remain in an unusable or hazardous condition for decades. As well, it will possibly take many years to remedy polluted groundwater by changing N practices at the soil surface (Pettyjohn, 1979; Croll, 1994). Thus, there is a need to:

i- investigate NO_3^--N distributions in the cultivated fields. The investigations should be done on basis of designated time intervals to depths possibly larger than the root zone.

ii- observe NO_3^--N concentrations in drainage tiles and/or channels in the cultivated fields.

iii- monitor the changes in concentrations of NO_3^--N in water pumped from underground.

iv- regulate the use of N fertilisers, FYM, and other agro-chemicals on the basis of best management.

5.3- COMPUTER MODELING:

The reader of this thesis may be surprised that no results from computer works are indicated in the text. There is no doubt that computer models can provide a very useful tool in the analysis of water, nitrogen, and solute management. Indeed within the Ph.D. study, an attempt was made to simulate the processes in the leaching columns.

Nitrogen leaching models consist of two main components. The first is a description of the hydrology of the soil. In the case of the columns used in this study the flow of water was transient, predominantly unsaturated with a water table lower boundary condition where the leachate drained from the column. The description of this flow regime relies on careful statements about the boundary conditions and about the parameters controlling flow, in particular those changing with water content in the soil such as the hydraulic conductivity and the vertical change in these parameters. In the case of the soil columns used here (and indeed in the sandy soils under irrigation in Saudi Arabia) the hydraulic conductivity function is not known. Indeed estimates based on the water release characteristic are prone to error because of the rapid drainage rate of these soils. This complication means that the function may have to be chosen arbitrarily to fit the observed data.

The second component in the models is the mineralisation rates for the organic matter in the soil. Hutson & Wagenet (1991) state that the crucial first step in using N leaching models (e.g., LEACH-N) is to estimate the rate at which added organic materials decompose. As part of this work the LEACH-N model (Hutson & Wagenet, 1992) was investigated. Poor simulations were observed and the reason for this is

unclear, but is probably due to a combination of the lack of precision of both the hydraulic parameters and the N mineralisation factors.

Further work should certainly consider the use of N leaching models, a review of which is provided by several workers (e.g., Tanji, 1982; Addiscott & Wagenet, 1985). However, it is clear that an independent estimate of the controlling parameters must be made before satisfactory and reliable simulation can be undertaken. It is the intent of the author to pursue this aspect of the research in the Kingdom of Saudi Arabia alongside the application of the findings of the laboratory experiments provided in this study.

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APPENDICES

APPENDIX A-1

METHODS OF ANALYSIS

It has been already indicated in Experiments One, Two, and Three (Chapters Three, Four, and Five, respectively) of the research study that different methods of analysis have been used, in which various analytical equipments have been employed. The analyses were carried out in the Analytical Laboratory, Department of Agricultural Water Management and the Soil Laboratory, Department of Agricultural Engineering and Environment in the School of Agriculture, Food and Environment, Cranfield University.

The aim of this appendix is to discuss the precision and reliability of the methods and equipments used. Emphasis is on those used for the analysis of N different forms and chloride (Cl^-).

1- N ANALYSES:

As indicated in the Experiments conducted in the current study, the N analysis involved the determinations of NO_3^--N, NH_4^+-N, and TSN in the effluent samples and the TN in the soil samples. The following sections discuss the methods and equipments used to analyse these N species.

1-A- NO_3^--N AND NH_4^+-N ANALYSIS:

Both were determined using the Technicon Auto-Analyzer II, which was assembled with different channels for each N species. The system was designed to accomplish the analysis in batches of 10 samples separated by a standard (i.e., drift) and two deionized water samples, which were used to determine the drifting patterns from the baseline occurring during the analysis. The maximum allowable drift was ±10%.

For every analysis, 6 standards were used at the beginning of the run to produce a calibration curve with a middle standard repeatedly used as the drift. The concentrations of the N species in the samples were then calculated automatically from the calibration curve, provided the least acceptable correlation coefficients (r) of 0.998. The original point of the X-Y curve was the starting point of any calibration curve.

Two different ranges of analysis were used for each N species. For NO_3^--N, they were from 0.05 to 25 and from 0.05 to 2 mg NO_3^--N l^{-1}. For NH_4^+-N, they were from

0.02 to 25 and from 0.02 to 5 mg NH_4^+-N l^{-1}. They were used according to the concentration of N species in the samples.

The performance of the system have been examined several times by the Aqua Check Test (Water research Centre, WRc) and proved to be sufficiently precise. Examples of the results of these tests are summarised in Table A-1.1.

1.B- TSN ANALYSIS:

All TSN values were determined by the autoclave method (Williams. ***et al.***, 1995). The method is summarised in two major steps. One is the oxidation step in which the sample is mixed with the oxidizing reagent of potassium persulphate (i.e., 4 ml samples and 6 ml $K_2S_2O_8$, respectively) and then autoclaved for 30 minutes at 110°C under 1 bar pressure. The second is the analytical step in which concentration was determined as NO_3^--N by the Technicon Auto-Analyzer II.

Two standards (i.e., EDTA or urea) and two deionized water samples at least were used as a check reference in every run. The runs were accepted when the average recovered values of the standards were within ±10% of full recovery.

The method was calibrated using prepared solutions from the EDTA and urea with different N concentrations (Figure A-1.1). The recovery percentages ranged between 104 and 107% and between 102 and 106% for the EDTA and urea, respectively. This shows that the method is appropriate to recover total N soluble in water.

1-C- TN ANALYSIS:

As already indicated in the Experiments undertaken, all TN values were determined using the BUCHI equipment. The equipment is a modified version from the Kjeldahl.

The method consists of three major steps which are digestion, distillation, and titration. The digestion step involved the use of 98% sulphuric acid (i.e., H_2SO_4 of 1.84 sp. gravity) with 2 Kjeltabs C tablets (i.e., a catalyst containing 5 gm K_2SO_4 and 0.1 gm $CuSO_4.5H_2O$) mixed with the sample in a digesting tube and then heated at 380°C until the sample is clear. The distillation was done in an alkaline solution (i.e., 40% of NaOH), which enhanced the conversion of the reduced NH_4^+-N into volatilised

NH_3 received in 1% boric acid containing the mixing indicator of SHER. Diluted H_2SO_4 was used in the titration step. The concentrations of H_2SO_4 used were chosen on the basis of N content expected in the samples.

This equipment was also calibrated and showed a good accuracy. The calibration was achieved using chemical compounds with known N contents. A field soil was also used in the calibration test. The N content in the soil was previously determined by Kjeldahl analysis in the Soil Survey and Land Research Centre, Cranfield University. The results of the calibration test are shown in Figure A-1.2. The figure shows that the method and the equipment were adequately reliable.

2- CHLORIDE ANALYSIS:

It has been already indicated (Section 3.2.1, Chapter Five) that Cl^- analysis was done using the Technicon Auto-Analyzer II, using the Cl^- channel attached to it.

The format of the analytical method used for Cl^- was similar to those used for NO_3^--N and NH_4^+-N. 10 batches of samples separated by the drift and waters were used. 6 standards covering a range from 0.02 to 50 mg Cl^- l^{-1} were used in the analysis. The drift was within the ±10% maximum limit, and the minimum r was 0.998. The accuracy of the method was also examined by the Aqua Check Test (Table A-1.1), which proved that the method is appropriate.

3- CONCLUSIONS:

In a conclusion to this discussion, the methods and equipment used in the undertaken study were adequately precise. Thus, the results obtained in the study are sufficiently accurate to measure the values and trends observed.

Table A-1.1. Samples of the aqua check results for the different N forms analyzed by the Technicon Auto-analyzer II.

Date	NO_3^--N		NH_4^+-N		Cl^-	
	mg l^{-1}	dif. %	mg l^{-1}	dif. %	mg l^{-1}	dif. %
20 March 1996	5.942	-3	9.040	0	45.160	-4
18 July 1996	3.270	-4	15.650	4	15.980	6

N.B.: Dif. % refers to the percentage of the differences between the measured value and the WRc value (i.e., reference).

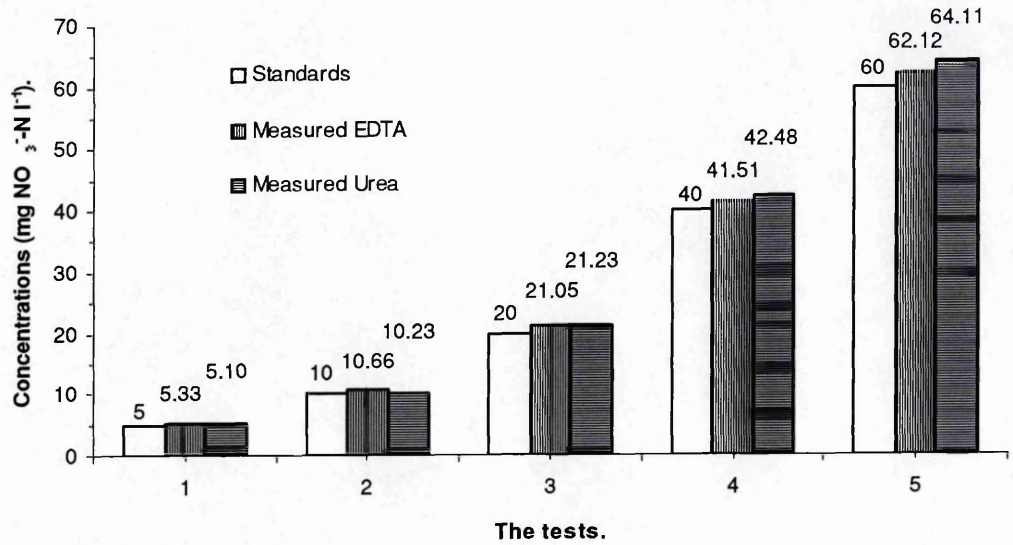

Figure A-1.1. The results of the calibration test for the TSN method (the values are presented on top of the bars)

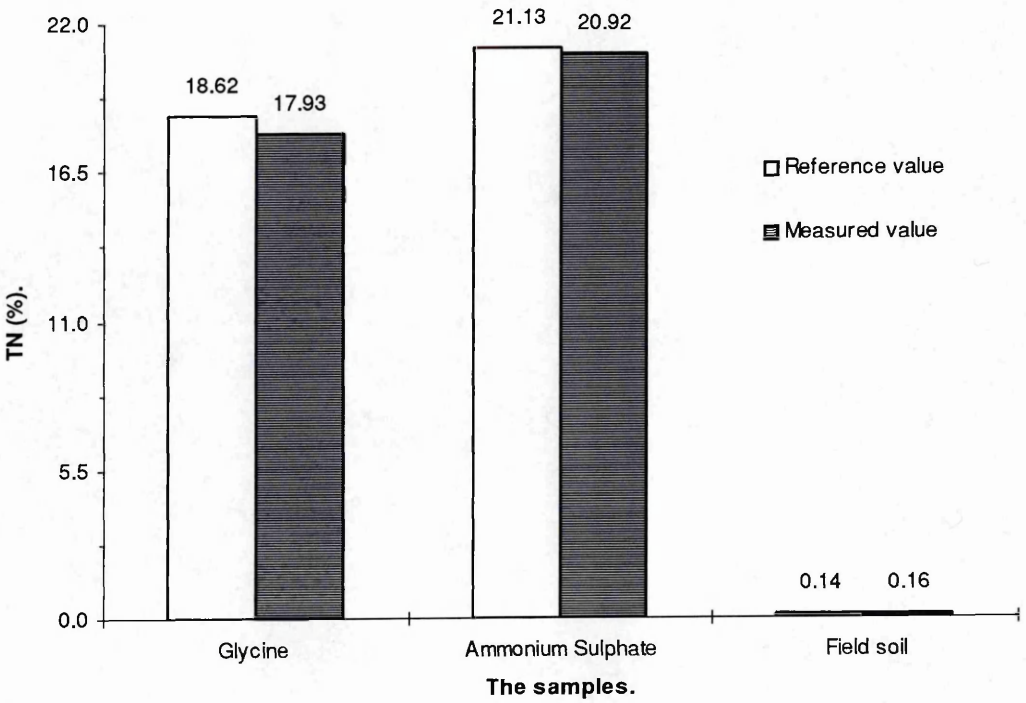

Figure A-1.2. The calibration test for the TN method using the BUCHI equipment (the values are presented on top of the bars).

APPENDIX A-2

Appendix A-2.1. A summary of different climatic values for the major agricultural areas in the KSA (Transworld, 1992).

Location	T °C			SR	RH	Monthly E	Wind	Annual Rainfall
	Max	Min	Mean	langley	%	mm	km hr^{-1}	mm
Riyadh (C)	47.0	-2.0	24.7	3988	25.4	247	4.7	74.0
Kharj (C)	49.0	-3.0	25.4	4230	30.2	294	3.9	61.3
Hofuf (E)	48.5	1.0	25.2	4241	48.3	268	3.0	69.0
Shaqra (C)	48.0	-0.5	25.3	4170	32.2	295	n.a.	1222.5
Majmaah (C)	48.0	0	24.4	3919	n.a.	365	6.9	114.6
Gassim (C)	47.9	-2.0	24.5	3964	29.6	304	6.6	19.4
Hail (N)	44.5	-4.0	22.0	3582	31.4	336	9.4	91.4
Tabuk (N)	46.5	-3.0	21.8	3237	35.0	321	5.3	19.4
Sakaka (N)	48.0	-4.7	23.1	3535	41.0	330	5.1	26.4
Madinah (W)	47.0	1.0	27.1	4633	31.3	404	5.5	26.7
Taif (W)	40.0	3.3	21.5	2708	41.3	245	3.8	140.9
Biljurshi (SW)	37.0	1.9	19.2	2147	54.8	182	3.3	418.4
Bishah (SW)	43.0	3.6	24.8	3817	45.1	292	n.a.	96.5
Abha (SW)	31.0	5.0	18.0	1714	57.3	250	8.0	320.9
Najran (SW)	45.0	1.8	23.4	3529	35.5	282	4.0	77.6
Jizan (SW)	45.0	18.0	30.4	6261	31.9	294	7.2	317.6
average	44.7	1.0	23.8	3730	35.9	294	5.5	124.8

N. B.: letters between parentheses refer to the regions as follows: C is central, E is eastern, N is northern, SW is southwestern, and W is western.

Appendix A-2.2. Soil associations, extent and main characteristics of soils in the KSA (MAW, 1995).

Soil association	Extent (ha)	Main characteristics
Calciorthids (haplic Calcisols)	17,720,300	Deep, loamy, arable soils.
Torriorthents-Calciorthids-rock outcrop (Calcaric Regosols- Lithic Leptosols- Haplic Calcisols-Rock outcrop)	42,837,200	Shallow, non-arable soils- some deep and moderately deep, loamy, arable soils- and steep rock outcrops.
Camborthids (Calcaric Cambisols)	2,402,000	Deep, loamy, arable soils.
Gypsiorthids-Calciorthids (Petric Gypsisols- Gypsic Solonchaks-Haplic Calcisols)	16,227,700	Shallow, non-arable soils- and deep, loamy, arable soils.
Torrifluvents-Calciorthids (Calcaric Fluvisols- Calcaric Arenosols-Haplic Calcisols)	1,306,000	Deep, loamy (some gravely), arable soils.
Lava stones- Camborthids (Lava stones- Calcaric Cambisols)	6,611,800	Non-arable, stony land- and some deep, loamy, arable soils.
Torriorthents -Xerorthents- rock outcrop (Lithic/ Eutric Leptosols- Rock outcrop-Calcaric Regosols)	525,300	Shallow, non-arable soil- very steep outcrops- and some terraced, moderately deep loamy, arable soils.
Rock outcrop- Torriorthents (Rock outcrop- Lithic Leptosols- Calcaric Regosols)	53,672,800	Very steep rock outcrop- and some shallow non-arable soils.
Torripsamments- Torriorthents (Calcaric Arenosols- Lithic Leptosols)	80,059,700	Sand dunes- interdunal deep sandy (some arable) soils- some shallow, non-arable- and some plain, deep, sandy- arable soils.
Udipsamments- Torripsamments (Gleyic/ Calcaric Arenosols)	2,895,600	Marine flats and sand dunes- non-arable.
Haplaquepts- Eutrochrepts (Eutric Gleysols- Gleyic Cambisols)	28,300	Deep, loamy, wet, arable soils.
Salorthids (Salic Fluvisols- Water area)	613, 300	Deep, highly saline, loam, non-arable soils.

N.B.: the classification between parentheses are soil units according to FAO-UNESCO Revised Legend of the Soil Map of the World.

Appendix A-2.3. The lithological sequence of aquifers in the KSA (MAW, 1984).

Lithological sequence	Aquifers	
	principal	secondary
Quaternary and Tertiary		Alluvium
Pliocene and Miocene Clastic Rocks	Neogene	Basalt
Eocene Carbonate to Upper Cretaceous Rocks	Dammam Umm er Radhuma	Aruma
Middle and Lower Cretaceous Clastic Rocks	Wasia-Biyadh (Cretaceous Sands)	Sakaka
Middle and Lower Jurassic Cretaceous Carbonate Rocks		Buwaib, Yamama Sulay Arab Jubaila Hanifah
Middle and Lower Cretaceous Clastic and Carbonate Rocks		Dhruma
Jurassic, Triassic, and Minjur, Permian Clastic Rocks	Minjur/Dhruma	Jilh
Lowe Paleozoic Clastic Rocks	Tabuk Wajid Saq	Jauf

Appendix A-2.4. The summary of Saudi government subsidies for Agricultural Production (Joffe, 1985; EL-Mallakh, 1982)

Type	Amount	Source
Production Input:		
Fertilizer	50 % of cost	MAW
Animal Feed	50 5 of cost	SAAB
Potato Seed	5 tons free; SR 1,000/ton thereafter up to 15 tons	MAW
Machinery and Equipment:		
Poultry Equipment	30 % of cost	SAAB
Dairy Equipment	30 % of cost	SAAB
Engines and Pumps	50 % of cost	SAAB
Fish Trawlers	Variable	SAAB
Transportation:		
Air Transport of Cows	100 % of cost	SAAB
Output:		
Wheat	SR 3.5/kg[a]	GSFMO
Rice	SR 0.30/k[a]	MAW
Corn	SR 0.25/kg[a]	MAW
Millet/ Barley	SR 0.15/kg[a]	MAW
Dates	SR 0.25/kg[a]	MAW
Date Palms Planted	SR 50.0/tree	MAW
Agricultural Credit:		
All Types	Variable Conditions	SAAB
Agro-industrial Credit		
All Types	Variable Conditions	SIDF
Land Reclamation:		
Land Distribution	Free	MAW

N.B.: a refers to purchase price.
MAW is Ministry of Agriculture and Water.
SAAB is Saudi Arabian Agricultural Bank.
GSFMO is Grain Silos and Flour Milling Organization.
SIDF is Saudi Industry Development Fund.

APPENDIX A-3

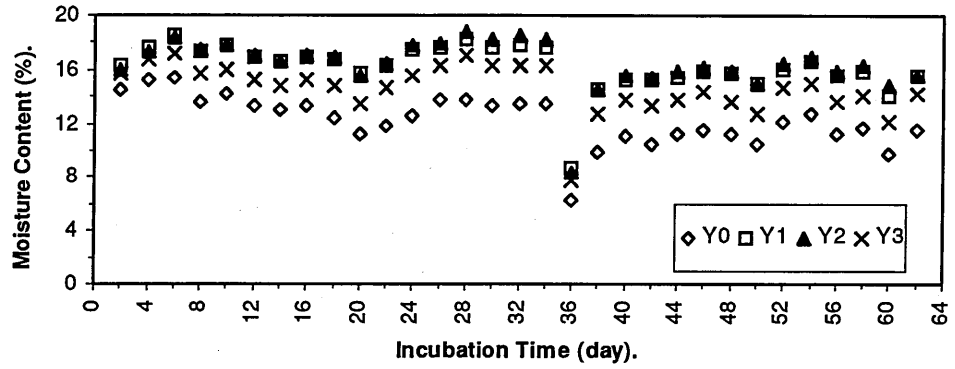

Figure A-3.1. The moisture condition of the FYM treatments prior to water application for the M1 treatment.

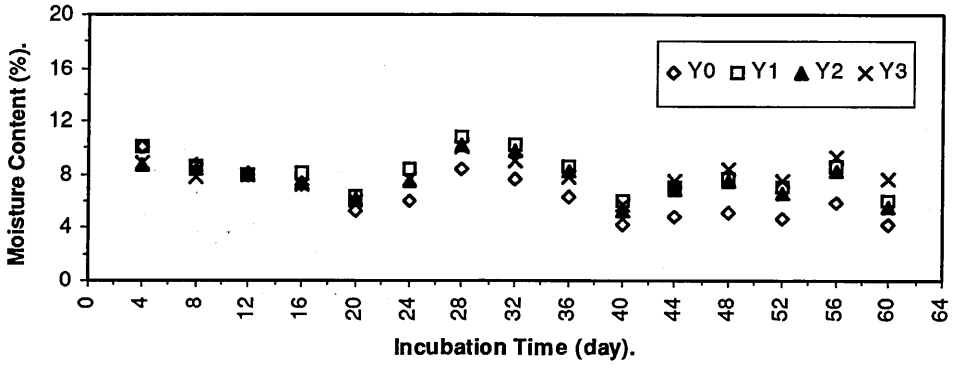

Figure A-3.2. The moisture condition of the FYM treatments prior to water application for the M2 treatment.

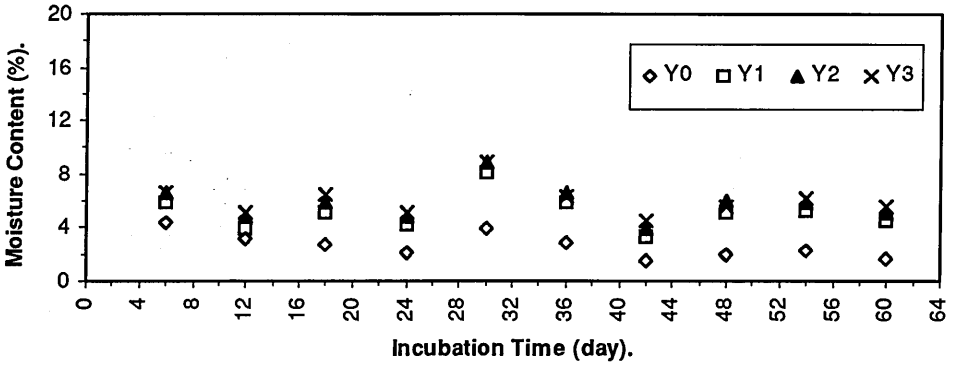

Figure A-3.3. The moisture condition of the FYM treatments prior to water application for the M3 treatment.

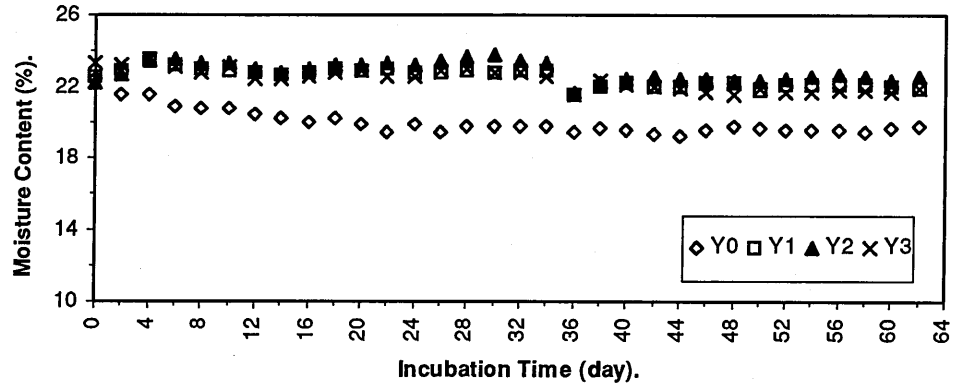

Figure A-3.4. The moisture condition of the FYM treatment after water application for the M1 treatment.

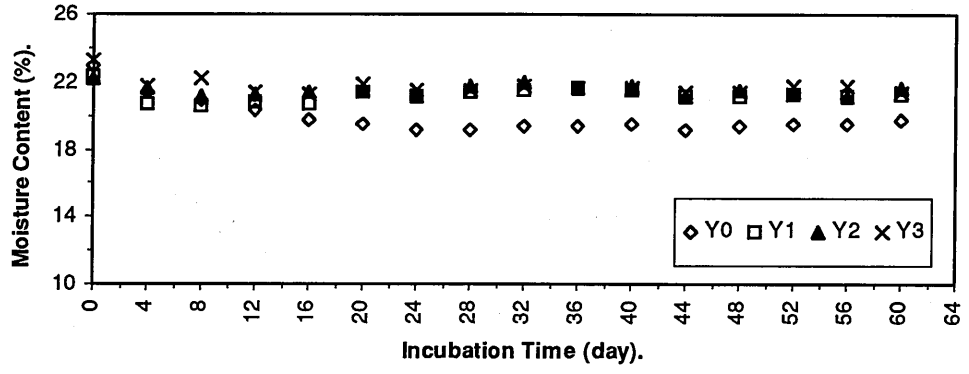

Figure A-3.5. The moisture condition of the FYM treatments after water application for the M2 treatment.

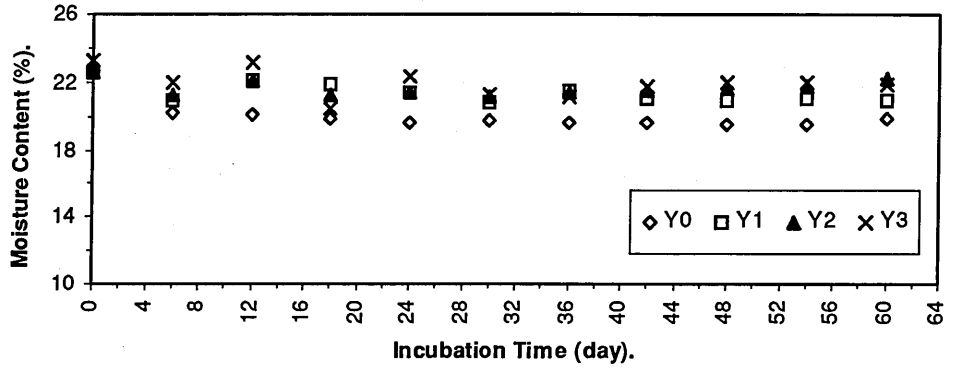

Figure A-3.6. The moisture condition of the FYM treatments after water application for the M3 treatment.

APPENDIX A-4

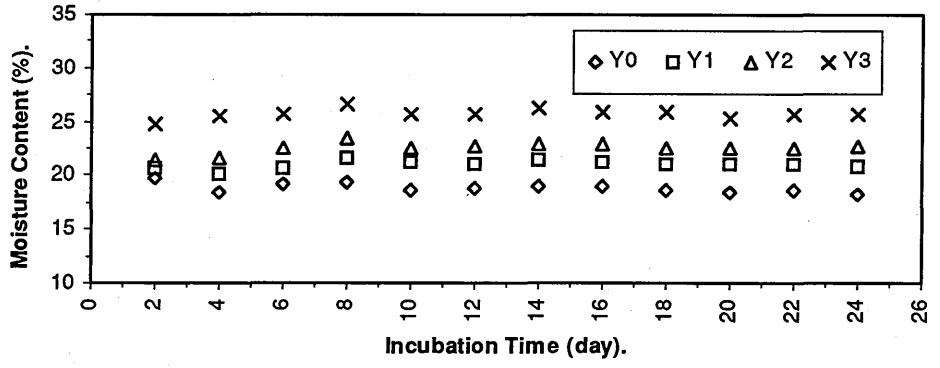

Figure A-4.1. The moisture conditions of the FYM treatments prior to water application for the M1 treatment.

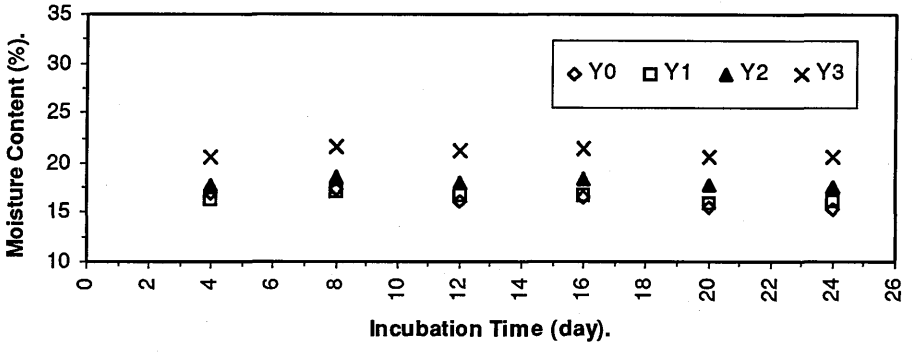

Figure A-4.2. The moisture conditions of the FYM treatments prior to water application for the M2 treatment.

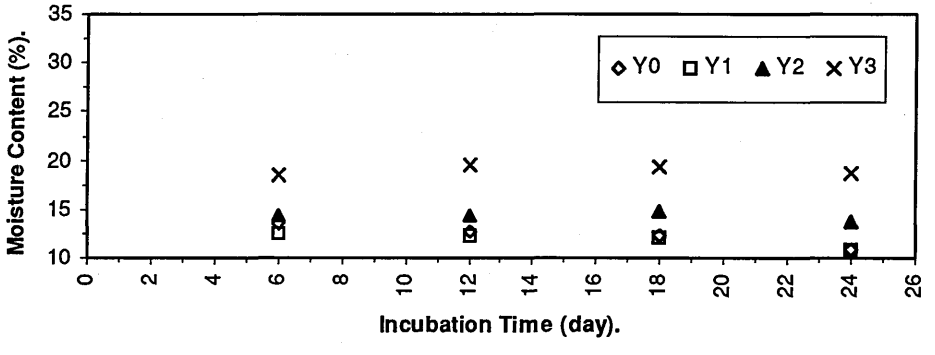

Figure A-4.3. The moisture conditions of the FYM treatments prior to water application for the M3 treatment.

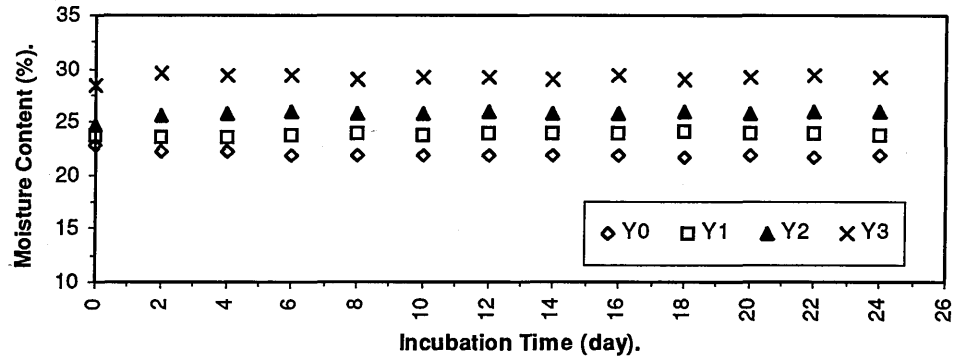

Figure A-4.4. The moisture conditions of the FYM treatments after water application for the M1 treatment.

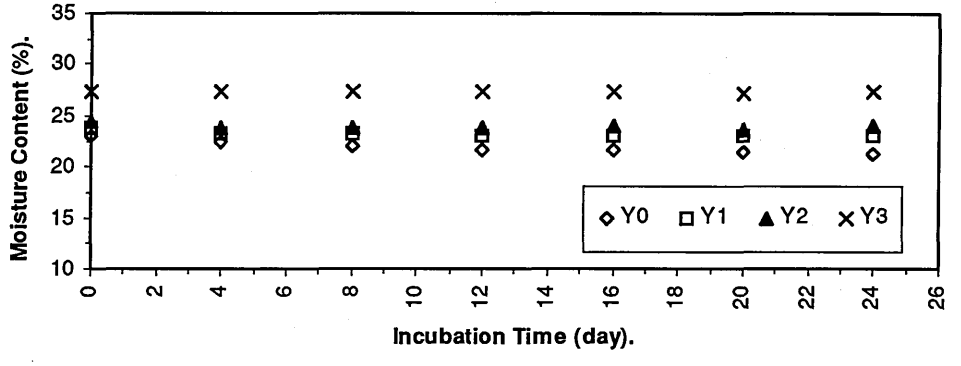

Figure A-4.5. The moisture conditions of the FYM treatments after water application for the M2 treatment.

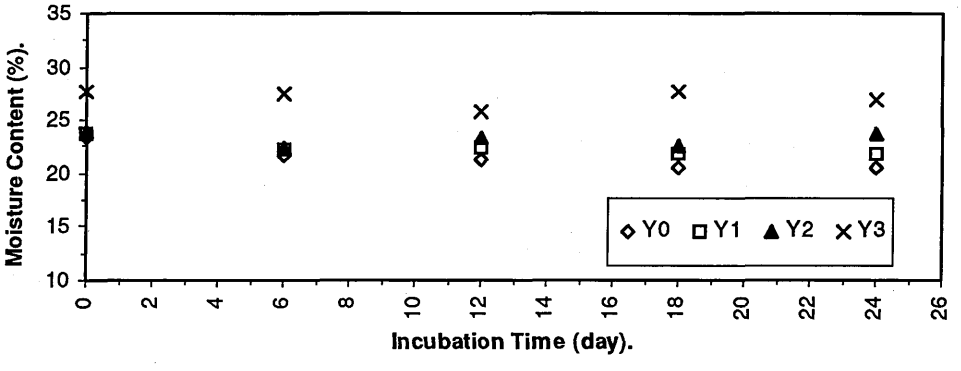

Figure A-4.6. The moisture conditions of the FYM treatments after water application for the M3 treatment.

APPENDIX A-5

APPENDIX A-5.1:

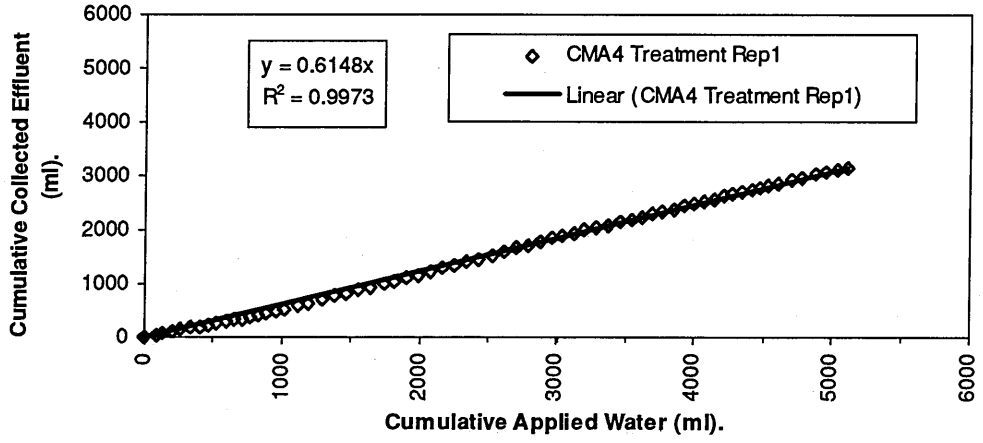

Figure A-5.1-A. Relationship between cumulative water yielded and applied column 1 CMA4 treatment.

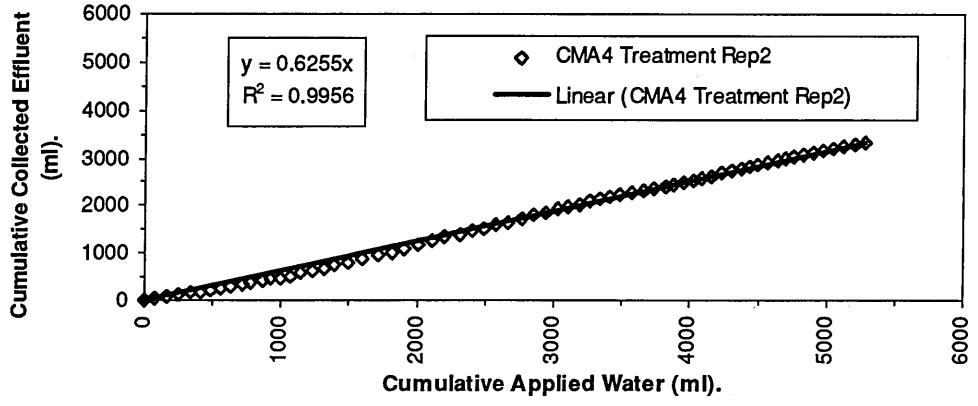

Figure A-5.1-B. Relationship between cumulative water yielded and applied column 2 CMA4 treatment.

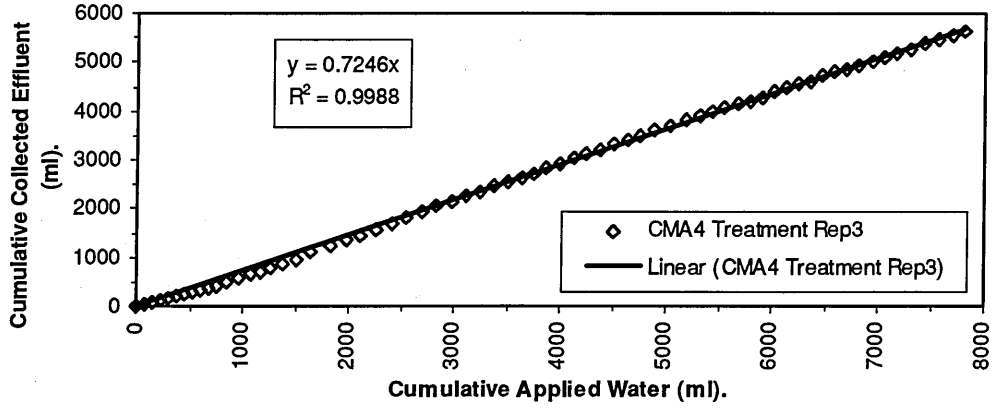

Figure A-5.1-C. Relationship between cumulative water yielded and applied column 3 CMA4 treatment.

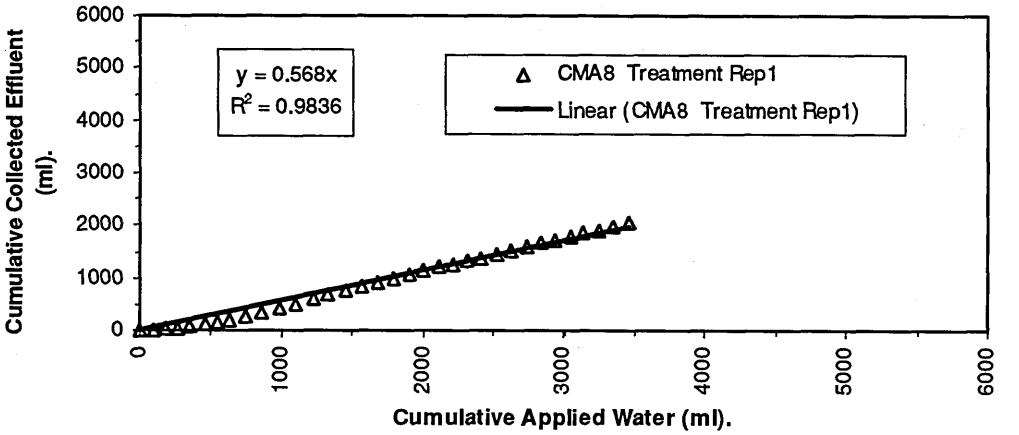

Figure A-5.1-D. Relationship between cumulative water yielded and applied column 1 CMA8 treatment.

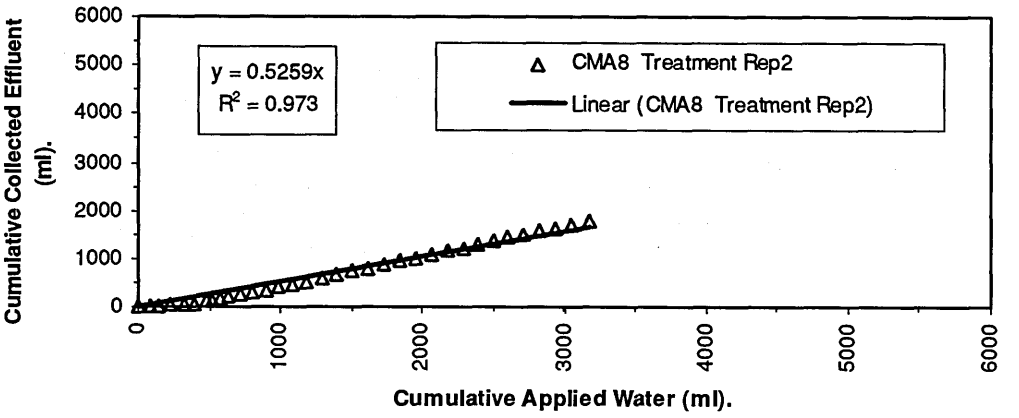

Figure A-5.1-E. Relationship between cumulative water yielded and applied column 2 CMA8 treatment.

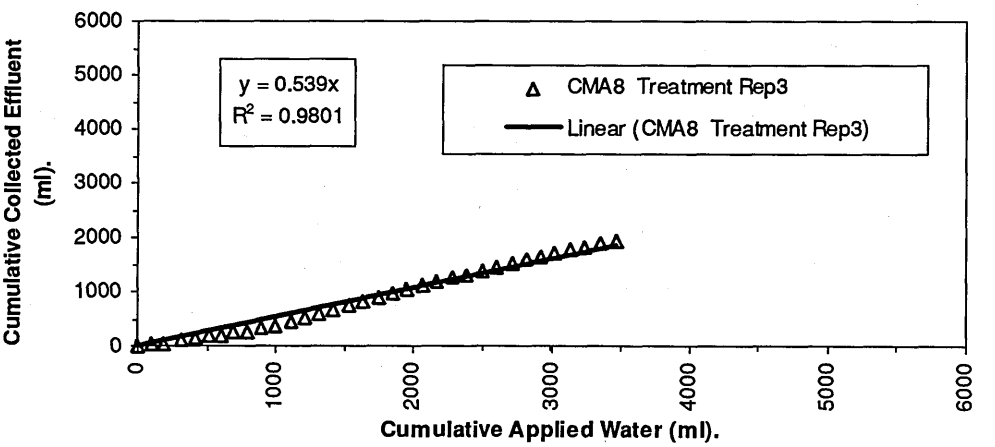

Figure A-5.1-F. Relationship between cumulative water yielded and applied column 3 CMA8 treatment.

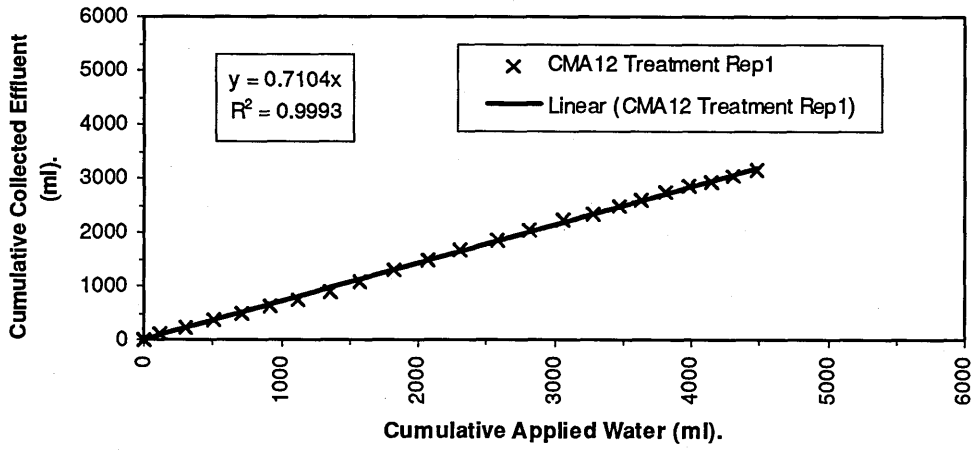

Figure A-5.1-G. Relationship between cumulative water yielded and applied column 1 CMA12 treatment.

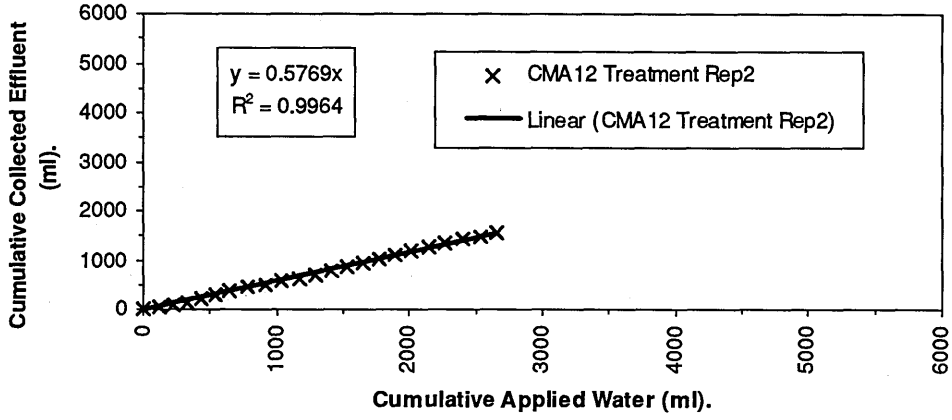

Figure A-5.1-H. Relationship between cumulative water yielded and applied column 2 CMA12 treatment.

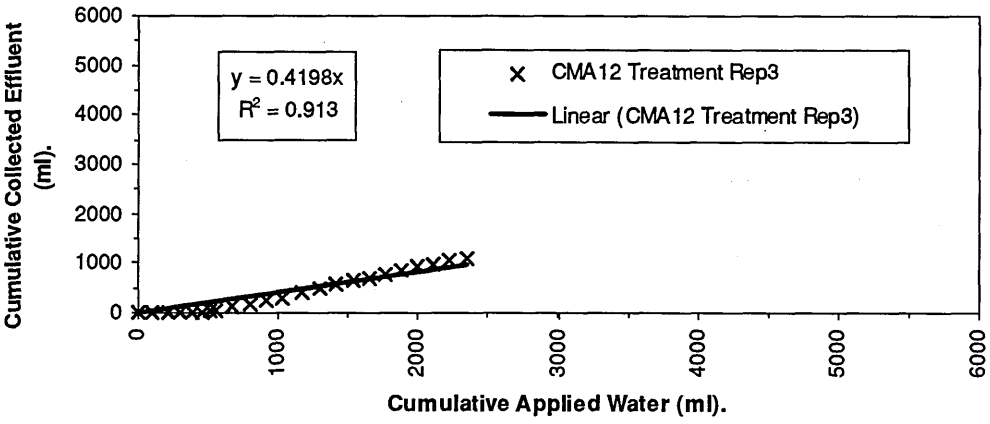

Figure A-5.1-I. Relationship between cumulative water yielded and applied column 3 CMA12 treatment.

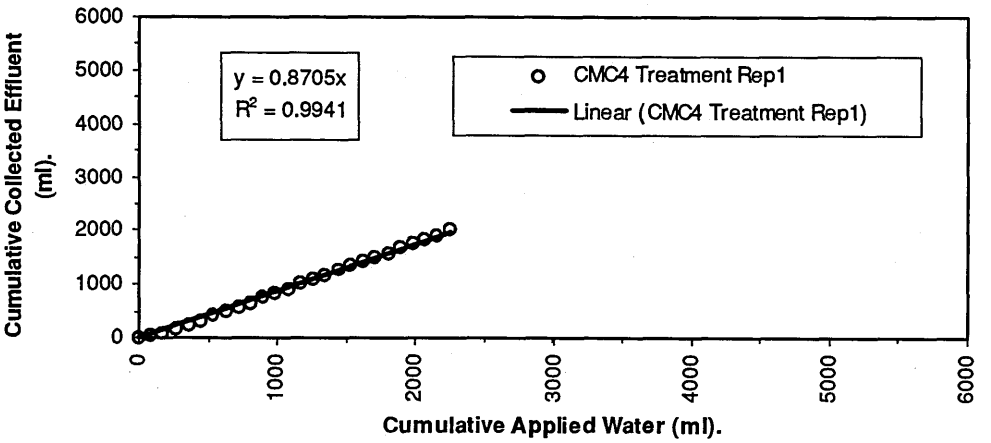

Figure A-5.1-J. Relationship between cumulative water yielded and applied column 1 CMC4 treatment.

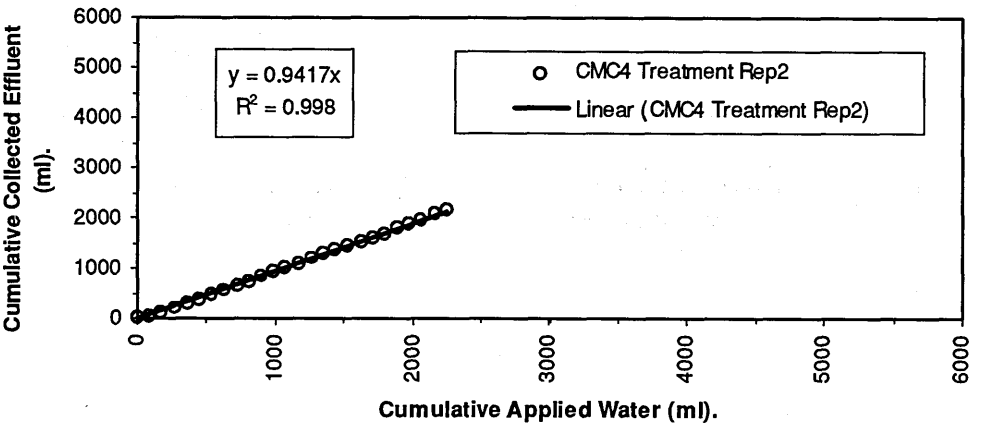

Figure A-5.1-K. Relationship between cumulative water yielded and applied column 2 CMC4 treatment.

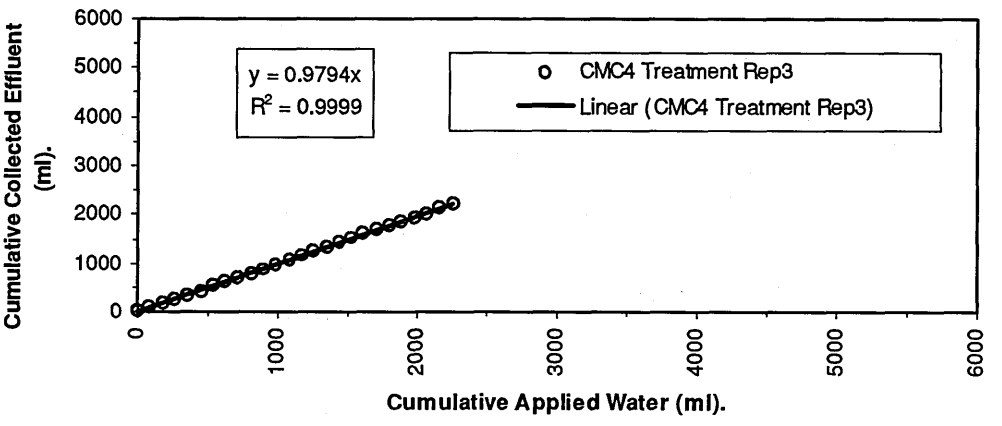

Figure A-5.1-L. Relationship between cumulative water yielded and applied column 3 CMC4 treatment.